INSTITUTION

OF

MECHANICAL ENGINEERS.

PROCEEDINGS.

1881.

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1881.

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1881.

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Edward A. Cowper,	London.

PAST-PRESIDENTS.

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Robert Napier,	(*deceased* 1876).
John Penn, F.R.S.,	(*deceased* 1878).
George Stephenson,	(*deceased* 1848).
Robert Stephenson, F.R.S.,	(*deceased* 1859).

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Joseph Tomlinson, Jun.,	London.
R. Price Williams,	London.

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Thomas Druitt.

SECRETARY.

Walter R. Browne.

ASSISTANT SECRETARY.

Alfred Bache.

LIST OF MEMBERS,

WITH YEAR OF ELECTION.

1881.

HONORARY LIFE MEMBERS.

1865. Downing, Samuel, LL.D., Trinity College, Dublin; and 4 The Hill, Monkstown, near Dublin.
1878. Lindsay, Lord, M.P., F.R.S., 47 Brook Street, Grosvenor Square, London, W.; and Haigh Hall, Wigan.
1878. Rayleigh, Lord, F.R.S., 4 Carlton Gardens, London, S.W.; and Terling Place, Witham, Essex.
1867. Tresca, Henri, Engineer Sub-Director, Conservatoire National des Arts et Métiers, Paris.

MEMBERS.

1878. Abbott, Thomas, Northgate Iron Works, Newark.
1861. Abel, Charles Denton, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C.
1874. Abernethy, James, 4 Delahay Street, Westminster, S.W.
1876. Adams, Henry, 60 Queen Victoria Street, London, E.C.
1875. Adams, Thomas, Ant and Bee Works, West Gorton, Manchester.
1879. Adams, William, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.W.
1848. Adams, William Alexander, Gaines, Worcester.
1881. Adams, William John, Messrs. Everitt Adams and Co., 35 Queen Victoria Street, London, E.C.

1859. Adamson, Daniel, Engineering Works, Dukinfield, near Manchester; and The Towers, Didsbury, Manchester.
1871. Adamson, Joseph, Messrs. Joseph Adamson and Co., Hyde, near Manchester.
1878. Adcock, Francis Louis, Post Office, Cape Town, Cape of Good Hope: (or care of William R. Adcock, 17 Rue Neuve de Berry, Havre, France.)
1851. Addison, John, 6 Delahay Street, Westminster, S.W.
1858. Albaret, Auguste, Engine Works, Liancourt-Rantigny, Oise, France.
1870. Alexander, Alfred, King William's Town, Cape of Good Hope: (or care of William Alexander, East Cranhams, Cirencester.)
1847. Allan, Alexander, Glen House, The Valley, Scarborough.
1875. Allan, George, Savile Street Engineering Works, Sheffield.
1881. Allen, Percy Ruskin, Anglo-American Brush Electric Light Co., Vine Street, York Road, Lambeth, London, S.E.
1865. Allen, William Daniel, Bessemer Steel Works, Sheffield.
1870. Alley, John, Engineer and Contractor, Moscow.
1877. Alley, Stephen, Messrs. Alley and MacLellan, 2 Peel Street, London Road, Glasgow.
1865. Alleyne, Sir John Gay Newton, Bart., Chevin, Belper.
1872. Alliott, James Bingham, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham.
1876. Allport, Charles James, 11 Queen Victoria Street, London, E.C.
1871. Allport, Howard Aston, Bestwood Coal and Iron Co., Nottingham; and The Park, Nottingham.
1861. Amos, Charles Edwards, 5 Cedars Road, Clapham Common, London, S.W.
1867. Amos, James Chapman, West Barnet Lodge, Lyonsdown, Barnet.
1876. Anderson, Henry John Card, 42 Queen Anne's Gate, Westminster, S.W.
1880. Anderson, James, Vyksounsky Iron Works, Mouram, Russia.
1856. Anderson, Sir John, LL.D., F.R.S.E., Fairleigh, The Mount, St. Leonard's-on-Sea.
1881. Anderson, Joseph Liddell, Messrs. Anderson and Gallwey, 8 Buckingham Street, Adelphi, London, W.C.
1856. Anderson, William, Messrs. Easton and Anderson, Erith Iron Works, Erith, London, S.E.; and 3 Whitehall Place, London, S.W.
1878. Angas, William Moore, Imperial College of Engineering, Tokei, Japan: (or care of G. D. Angas, Neswick, Driffield.)
1858. Appleby, Charles Edward, Charing Cross Chambers, Duke Street, Adelphi, London, W.C.
1867. Appleby, Charles James, Messrs. Appleby Brothers, 89 Cannon Street, London, E.C.; and East Greenwich Works, London, S.E.

1874. Aramburu y Silva, Fernando, Messrs. Aramburu and Sons, Cartridge Manufacturers, Calle de la Virgen de las Azucenas, Madrid: (or care of Manuel Cardenosa, 86 Great Tower Street, London, E.C.)

1881. Archbold, Joseph Gibson, Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.

1874. Archer, David, General Manager, Messrs. Brown Marshalls and Co., Britannia Railway Carriage and Wagon Works, Birmingham.

1859. Armitage, William James, Farnley Iron Works, Leeds.

1879. Armstrong, Alexander, Vulcan Foundry, Leet Street, Invercargill, Otago, New Zealand.

1866. Armstrong, George, Great Western Railway, Locomotive Department, Stafford Road Works, Wolverhampton.

1863. Armstrong, John, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.

1876. Armstrong, William, Jun., Mining Engineer, Wingate Colliery, County Durham.

1858. Armstrong, Sir William George, C.B., D.C.L., LL.D., F.R.S., Elswick, Newcastle-on-Tyne; and Cragside, Morpeth.

1870. Armstrong, William Irving, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.

1873. Arnold, David Nelson, Manager, Midland Wagon Works, Lander Street, Birmingham.

1879. Arrol, Thomas Arthur, Manager, Messrs. P. and W. MacLellan, Clutha Iron Works, Glasgow.

1857. Ashbury, James Lloyd, 6 Eastern Terrace, Brighton.

1873. Ashbury, Thomas, Managing Director, Ashbury Railway Carriage and Iron Works, Openshaw, Manchester; and 215 Plymouth Grove, Manchester. (*Life Member.*)

1881. Aspinall, John Audley Frederick, Assistant Locomotive Engineer, Great Southern and Western Railway, Dublin.

1877. Astbury, James, Smethwick Foundry, near Birmingham.

1870. Atkinson, Charles Fanshawe, Messrs. Marriott and Atkinson, Fitzalan Steel Works, Sheffield.

1875. Atkinson, Edward, Messrs. Richards and Atkinson, Bank Street, Royal Exchange, Manchester; and 4 Richmond Hill, Bowdon, Cheshire. (*Life Member.*)

1869. Austin, William Lawson, Messrs. Austin and Dodson, Cambria Steel and File Works, Arundel Street, Sheffield.

1869. Aveling, Thomas, Messrs. Aveling and Porter, Rochester.

1872. Bagshaw, Walter, Messrs. J. Bagshaw and Sons, Victoria Foundry, Batley.

1865. Bailey, John, Messrs. Courtney Stephens and Bailey, Blackhall Place Iron Works, Dublin.

1860. Bailey, Samuel, Mining Engineer, Perry Pont House, Perry Barr, Birmingham.

1880. Baillie, Robert, Messrs. Westwood Baillie and Co., London Yard Iron Works, Poplar, London, E.

1872. Bailly, Philimond, 62 Rue de la Victoire, Paris.

1880. Bain, William Neish, Messrs. Kyle and Bain, Hong Kong Ice Works, Eastpoint, Hong Kong, China: (or care of George Ogilvie, 110 George Street, Glasgow.)

1873. Baird, George, St. Petersburg; and 5A Cork Street, Burlington Gardens, London, W.

1866. Baker, Samuel, Engine and Boiler Works, 22 Oil Street, Liverpool.

1875. Bakewell, Herbert James, Engineer, Department of the Controller of the Navy, Admiralty, Whitehall, London, S.W.

1879. Baldwin, Thomas, Chief Engineer, Mutual Boiler Insurance Company, Victoria Street, Manchester.

1877. Bale, Manfred Powis, 20 Budge Row, Cannon Street, London, E.C.

1879. Banderali, David, Assistant Locomotive and Carriage Superintendent, Chemin de fer du Nord, Paris.

1870. Barber, Thomas, Mining Engineer, High Park Collieries, Eastwood, Nottinghamshire.

1870. Barclay, Arthur, 12 York Street, Covent Garden, London, W.C.

1860. Barker, Paul, Church Road, Yardley, near Birmingham.

1875. Barlow, William Henry, F.R.S., 2 Old Palace Yard, Westminster, S.W.

1866. Barnard, Clement, 4 Billiter Square, London, E.C.

1881. Barnett, John Davis, Assistant Mechanical Superintendent, Western Division, Grand Trunk Railway, Stratford, Ontario, Canada.

1878. Barr, James, Works Manager, Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow.

1879. Barratt, Samuel, Engineer and Manager, Corporation Gas Works, Gaythorn Station, Hulme, Manchester.

1862. Barrow, Joseph, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.

1867. Barrows, Thomas Welch, Messrs. Barrows and Stewart, Portable Engine Works, Banbury.

1871. Barry, John Wolfe, 23 Delahay Street, Westminster, S.W.

1860. Batho, William Fothergill, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1881. Bawden, William, Assistant Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1872. Bayliss, Thomas Richard, Adderley Park Rolling Mills and Metal Works, Birmingham; and Belmont, Northfield, Birmingham.

1877. Beale, William Phipson, 6 Stone Buildings, Lincoln's Inn, London, W.C.

1881. Beattie, Alfred Luther, Manager, New Zealand Railway Workshops, Dunedin, Otago, New Zealand.

1880. Beaumont, William Worby, 163 Strand, London, W.C.

1859. Beck, Edward, Dallam Forge, Warrington; and 21 Bold Street, Warrington. (*Life Member.*)

1873. Beck, William Henry, 139 Cannon Street, London, E.C.

1875. Beckwith, John Henry, Engineer to Messrs. W. and J. Galloway and Sons, Knott Mill Iron Works, Manchester.

1875. Beeley, Thomas, Engineer and Boiler Maker, Hyde Junction Iron Works, Hyde, near Manchester.

1858. Bell, Isaac Lowthian, F.R.S., Clarence Iron Works, Middlesbrough; and Rounton Grange, Northallerton; and 16 Eaton Place, London, S.W.

1880. Bell, William Henry, Sir W. G. Armstrong and Co., Central Chambers, Liverpool.

1879. Bellamy, Charles James, 38 Parliament Street, Westminster, S.W

1857. Bellhouse, Edward Taylor, Eagle Foundry and Iron Works, Hunt Street, Oxford Street, Manchester.

1868. Belliss, George Edward, Steam Engine and Boiler Works, Ledsam Street, Birmingham.

1878. Belsham, Maurice, 6A Victoria Street, Westminster, S.W.

1854. Bennett, Peter Duckworth, Horseley Iron Works, Tipton.

1877. Bennett, Thomas Oldham, Post Office, Melbourne, Victoria.

1872. Bennett, William, Jun., 38 Sir Thomas' Buildings, Liverpool.

1879. Bergeron, Charles, 2 Edinburgh Mansions, Victoria Street, Westminster, S.W.

1861. Bessemer, Sir Henry, F.R.S., Denmark Hill, London, S.E.

1866. Bevis, Restel Ratsey, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead; and Manor Hill, Birkenhead.

1874. Bewick, Thomas John, Mining Engineer, Haydon Bridge, Northumberland.

1870. Bewlay, Hubert, Birmingham Heath Boiler Works, Spring Hill, Birmingham.

1861. Binns, Charles, Mining Engineer, Clay Cross, near Chesterfield.

1877. Birch, Robert William Peregrine, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1847. Birley, Henry, Haigh Foundry, near Wigan.

1875. Bisset, William Harvey, Board of Trade Surveyor, St. Katharine Dock House, London, E.; and 45 Highbury Quadrant, London, N.

1879. Black, William, Messrs. Black Hawthorn and Co., Gateshead.

1862. Blake, Henry Wollaston, F.R.S., Messrs. James Watt and Co., 90 Leadenhall Street, London, E.C.

1881. Blechynden, Alfred, Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.

1867. Bleckly, John James, Bewsey Iron Works, Warrington; and Daresbury Lodge, Altrincham.

1881. Bocquet, William, Locomotive Engineer, Scinde Punjaub and Delhi Railway, Lahore, India; and 37 Kenyon Terrace, Claughton, Birkenhead.

1863. Boeddinghaus, Julius, Machine Works and Iron Foundry, Düsseldorf, Germany.

1880. Borodine, Alexander, Engineer-in-Chief, Russian South Western Railways, Kieff, Russia.

1869. Borrie, John, Norton, near Stockton-on-Tees.

1878. Bourdon, François Edouard, 74 Faubourg du Temple, Paris: (or care of Messrs. Negretti and Zambra, Holborn Viaduct, London, E.C.)

1879. Bourne, William Temple, Messrs. Bourne and Grove, Bridge Steam Saw Mills, Worcester.

1879. Bovey, Henry Taylor, Professor of Engineering, McGill University, Montreal, Canada.

1880. Bow, William, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley.

1870. Bower, Anthony, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool.

1858. Bower, John Wilkes, Lancashire and Yorkshire Railway, Engineer's Office, Manchester. (*Life Member.*)

1869. Boyd, William, Wallsend Slipway and Engineering Co., Wallsend, near Newcastle-on-Tyne.

1875. Braconnot, Capt. Carlos, Chief Director and Engineer of the Marine Arsenal, Correio Geral, Caixa 232, Rio de Janeiro, Brazil; and 17 bis, Boulevard Eugène, Neuilly, Seine, France: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)

1878. Bradley, Frederick Augustus, 39 Queen Victoria Street, London, E.C.

1881. Bradley, Thomas, Wellington Foundry, Newark.

1854. Bragge, William, Shirle Hill, Hamstead Road, Birmingham.

1878. Braithwaite, Charles C., 35 King William Street, London Bridge, London, E.C.

1875. Braithwaite, Richard Charles, Manager, Old Park Iron Works, Wednesbury.

1854. Bramwell, Sir Frederick Joseph, F.R.S., 37 Great George Street, Westminster, S.W.

1868. Breeden, Joseph, Messrs. Breeden and Booth, Cheapside Works, 157 Cheapside, Birmingham.

1881. Briggs, Robert, United States Engineer Office, 1125 Girard Street, Philadelphia, U.S.

1865. Brock, Walter, Messrs. Denny and Co., Engine Works, Dumbarton.
1879. Brodie, John Shanks, Assistant to Borough and Water Engineer, Municipal Offices, Liverpool.
1852. Brogden, Henry, Hale Lodge, Altrincham, near Manchester. (*Life Member.*)
1877. Bromley, Massey, Locomotive Superintendent, Great Eastern Railway Stratford, London, E.
1880. Brophy, Michael Mary, Messrs. James Slater and Co., 251 High Holborn, London, W.C.
1874. Brotherhood, Peter, Belvedere Road, Lambeth, London, S.E.; and 25 Ladbroke Gardens, Notting Hill, London, W.
1866. Brown, Andrew Betts, Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.
1879. Brown, Charles, Manager, Swiss Locomotive and Machine Works, Winterthur, Switzerland: (or care of Dr. Gardiner Brown, 9 St. Thomas' Street, London Bridge, London, S.E.)
1880. Brown, Francis Robert Fountaine, Manager, Grand Trunk Railway Locomotive Works, Montreal, Canada.
1881. Brown, George William, Reading Iron Works, Reading.
1863. Brown, Henry, Waterloo Chambers, Waterloo Street, Birmingham.
1869. Browne, Benjamin Chapman, Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.
1874. Browne, Tomyns Reginald, Assistant District Locomotive Superintendent, East Indian Railway, Allahabad, India: (or care of Messrs. B. Smyth and Co., 1 New China Bazaar Street, Calcutta.)
1869. Browne, Walter Raleigh, 10 Victoria Chambers, Victoria Street, Westminster, S.W.
1874. Bruce, George Barclay, 2 Westminster Chambers, Victoria Street, Westminster, S.W.
1867. Bruce, William Duff, Vice-Chairman, Port Commission, Calcutta; and 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1873. Brunel, Henry Marc, 23 Delahay Street, Westminster, S.W.
1870. Brunlees, James, 5 Victoria Street, Westminster, S.W.
1872. Brunner, Henry, Messrs. John Hutchinson and Co., Alkali Works, Widnes; and Cliff House, Appleton, Widnes.
1866. Bryham, William, Rose Bridge and Douglas Bank Collieries, near Wigan.
1873. Buckley, Robert Burton, Executive Engineer, Indian Public Works Department, Seebpore, Calcutta: (or care of H. Burton Buckley, 1 St. Mary's Terrace, Paddington, London, W.)
1877. Buckley, Samuel, Messrs. Buckley and Taylor, Castle Iron Works, Oldham.
1874. Buddicom, William Barber, Penbedw Hall, Mold, Flintshire.

1872. Budenberg, Arnold, Messrs. Schaeffer and Budenberg, 1 Southgate, St. Mary's Street, Manchester.
1881. Bulkley, Henry Wheeler, 149 Broadway, New York.
1877. Burgess, James Fletcher, Messrs. Ormerod Grierson and Co., 5 Westminster Chambers, Victoria Street, Westminster, S.W.
1881. Burn, Robert Scott, Oak Lea, Edgeley Road, near Stockport.
1874. Burn, William Edward, 173 Portland Road, Newcastle-on-Tyne.
1878. Burnett, Robert Harvey, Locomotive Superintendent, Government Railways, Sydney, New South Wales: (or care of Messrs. Bicknell and Hortin, 161 Edgware Road, London, W.)
1878. Burrell, Charles, Jun., Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford.
1871. Burrows, James, Douglas Bank, Wigan.
1877. Burton, Clerke, Post Office Chambers, Bute Docks, Cardiff.
1870. Bury, William, 5 New London Street, London, E.C.
1856. Butler, Ambrose Edmund, Kirkstall Forge, near Leeds.
1859. Butler, John, Stanningley Iron Works, near Leeds.

1877. Campbell, Angus, Superintendent of the Government Foundry and Workshops, Roorkee, India.
1880. Campbell, Daniel, 3 Westminster Chambers, Victoria Street, Westminster, S.W.
1864. Campbell, David, 151 Eglinton Street, Glasgow.
1869. Campbell, James, Hunslet Engine Works, Leeds.
1860. Carbutt, Edward Hamer, M.P., 19 Hyde Park Gardens, London, W.; and Llanwern House, Monmouthshire.
1878. Cardew, Cornelius Edward, Deputy Locomotive and Carriage Superintendent, Rajputana State Railway, Ajmeer, India: (or care of Messrs. King, King and Co., Bombay.)
1875. Cardozo, Francisco Corrêa de Mesquita, Messrs. Cardozo and Irmâo, Pernambuco Engine Works, Pernambuco, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.) (*Life Member.*)
1878. Carlton, Thomas William, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C.
1869. Carpmael, Frederick, Highfield, Knockholt, near Sevenoaks.
1866. Carpmael, William, 24 Southampton Buildings, London, W.C.
1877. Carr, Robert, Resident Engineer, London and St. Katharine Docks Co., London Docks, Upper East Smithfield, London, E.
1874. Carrington, William T. H., 76 Cheapside, London, E.C.
1876. Carson, William, Egremont, Birkenhead.
1877. Carter, Claude, Manager, Messrs. Hetherington and Co., Ancoats Works, Pollard Street, Manchester.

1877. Carter, William, Managing Engineer, Birmingham Patent Tube Works, Smethwick, near Birmingham; and Imperial Tube Works, Birmingham.

1870. Carver, James, Lace Machine Works, Alfred Street, Nottingham.

1869. Caspersen, Hans William, Engineer, Danish Government Railway Service, 164 Rye Hill, Newcastle-on-Tyne.

1876. Challen, Stephen William, Messrs. Taylor and Challen, Derwent Foundry, 99 Constitution Hill, Birmingham.

1866. Chapman, Henry, 113 Victoria Street, Westminster, S.W.; and 10 Rue Laffitte, Paris.

1878. Chapman, James Gregson, Messrs. Fawcett Preston and Co., Phœnix Foundry, Liverpool; and 25 Austinfriars, London, E.C.

1878. Chappé de Leonval, Thomas Fletcher, 29 Stanley Gardens, Kensington Park, London, W.

1877. Chater, John, Messrs. Henry Pooley and Son, 89 Fleet Street, London, E.C.

1872. Chatwin, Thomas, Victoria Works, Great Tindal Street, Ladywood, Birmingham.

1867. Chatwood, Samuel, Lancashire Safe and Lock Works, Bolton; and Irwell House, Drinkwater Park, Prestwich, near Manchester.

1873. Cheesman, William Talbot, Hartlepool Rope Works, Hartlepool.

1881. Chilcott, William Winsland, Devonport Dockyard, Devonport.

1877. Chisholm, John, Messrs. William Muir and Co., Sherborne Street, Manchester; and 30 Devonshire Street, Higher Broughton, Manchester.

1857. Chrimes, Richard, Messrs. Guest and Chrimes, Brass Works, Rotherham.

1880. Churchward, George Dundas, Post Office, Launceston, Tasmania; and Kersney Manor, Dover.

1869. Clapham, Robert Calvert, Earsdon, near Newcastle-on-Tyne.

1871. Clark, Christopher Fisher, Mining Engineer, Garswood Coal and Iron Co., Park Lane Collieries, Wigan; and Cranbury Lodge, Park Lane, Wigan.

1878. Clark, Daniel Kinnear, 8 Buckingham Street, Adelphi, London, W.C.

1859. Clark, George, Southwick Engine Works, near Sunderland.

1867. Clark, George, Jun., Southwick Engine Works, near Sunderland.

1869. Clark, William, Mining Engineer, Teversall Collieries, near Mansfield.

1865. Clarke, John, Messrs. Hudswell Clarke and Rodgers, Railway Foundry, Jack Lane, Leeds.

1869. Clarke, William, Messrs. Clarke Chapman and Gurney, Victoria Works, South Shore, Gateshead.

1859. Clay, William, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead; and 45 North Corridor, The Albany, Liverpool.

1870. Clayton, Nathaniel, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.

1871. Cleminson, James, 7 Westminster Chambers, Victoria Street, Westminster, S.W.
1873. Clench, Frederick, Messrs. Robey and Co., Perseverance Iron Works, Lincoln.
1878. Closson, Prosper, 48 Rue Laffitte, Paris.
1881. Cochrane, Brodie, Mining Engineer, Aldin Grange, Durham.
1858. Cochrane, Charles, Woodside Iron Works, near Dudley; and The Grange, Stourbridge.
1869. Cochrane, Joseph Bramah, Woodside Iron Works, near Dudley.
1868. Cochrane, William, Mining Engineer, Elswick Colliery, Elswick, Newcastle-on-Tyne; and Oakfield House, Gosforth, Newcastle-on-Tyne.
1867. Cockey, Francis Christopher, Selwood Iron Works, Frome.
1864. Coddington, William, Ordnance Cotton Mill, Blackburn.
1876. Coe, William John, 1 Rumford Place, Liverpool.
1847. Coke, Richard George, Mining Engineer, 39 Holywell Street, Chesterfield; and Brimington Hall, near Chesterfield.
1878. Cole, John William, 54 King William Street, London, E.C.
1878. Coles, Henry James, Sumner Street, Southwark, London, S.E.
1877. Coley, Henry, Manager, Messrs. S. Owens and Co., Whitefriars Street, Fleet Street, London, E.C.
1878. Colyer, Frederick, 18 Great George Street, Westminster, S.W.
1874. Conyers, William, Dunedin, Otago, New Zealand.
1877. Cooper, Arthur, Engineer, Messrs. Brown Bailey and Dixon, Sheffield Steel and Iron Works, Sheffield.
1875. Cooper, Frederick, Chief Engineer, H. M. Gun Carriage Department, Bombay.
1877. Cooper, George, Engineer and General Manager, Buenos Ayres Great Southern Railway, Buenos Ayres: (or care of Secretary, Buenos Ayres Great Southern Railway, 4 Great Winchester Street, London, E.C.)
1874. Cooper, William, Neptune Foundry, Hull.
1881. Coote, Arthur, Messrs. Andrew Leslie and Co., Hebburn, Newcastle-on-Tyne.
1881. Copeland, Charles John, Messrs. Westray Copeland and Co., Barrow-in-Furness.
1878. Cornes, Cornelius, Manager, Messrs. Appleby Brothers, East Greenwich Works, London, S.E.
1848. Corry, Edward, 8 New Broad Street, London, E.C.
1881. Cosser, Thomas, McLeod Road Iron Works, Kurrachee, India.
1875. Cotton, Francis Michael, Messrs. Field Field and Cotton, Chandos Chambers, 22 Buckingham Street, Adelphi, London, W.C.

1875. Cottrill, Robert Nivin, Beehive Works, Bolton.
1868. Coulson, William, Mining Engineer, Shamrock House, Durham.
1878. Courtney, Frank Stuart, 3 Whitehall Place, London, S.W.
1875. Coward, Edward, Messrs. Melland and Coward, Cotton Mills and Bleach Works, Heaton Mersey, near Manchester.
1875. Cowen, Edward Samuel, Messrs. G. R. Cowen and Co., Beck Foundry, Brook Street, Nottingham; and 9 Rope Walk Street, Nottingham.
1870. Cowen, George Roberts, Messrs. G. R. Cowen and Co., Beck Foundry, Brook Street, Nottingham; and 9 Rope Walk Street, Nottingham.
1880. Cowper, Charles Edward, 6 Great George Street, Westminster, S.W.
1847. Cowper, Edward Alfred, 6 Great George Street, Westminster, S.W.
1878. Coxhead, Frederick Carley, 27 Leadenhall Street, London, E.C.
1847. Crampton, Thomas Russell, 4 Victoria Street, Westminster, S.W.
1871. Craven, Joseph, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.
1866. Craven, William, Vauxhall Iron Works, Osborne Street, Manchester.
1873. Crippin, Edward Frederic, Mining Engineer, Brynn Hall Colliery, Ashton, near Wigan.
1878. Crohn, Frederick William, 16 Burney Street, Greenwich, S.E.
1877. Crompton, Rookes Evelyn Bell, Messrs. T. H. P. Dennis and Co., Anchor Iron Works, Chelmsford; and Mansion House Buildings, Queen Victoria Street, London, E.C.
1881. Crosland, James Foyell Lovelock, Assistant Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.
1865. Cross, James, Messrs. John Hutchinson and Co., Alkali Works, Widnes; and Ditton Lodge, Warrington.
1871. Crossley, William, 153 Queen Street, Glasgow.
1875. Crossley, William John, Messrs. Crossley Brothers, Great Marlborough Street, Manchester.
1863. Crow, George, Messrs. R. Stephenson and Co., Newcastle-on-Tyne.
1874. Curry, William, Locomotive Superintendent, Great Northern Railway of Ireland, Dublin.
1875. Curtis, Richard, Messrs. Curtis Sons and Co., Phœnix Works, Chapel Street, Manchester.
1876. Cutler, Samuel, Providence Iron Works, Millwall, London, E.

1864. Daglish, George Heaton, St. Helen's Foundry, St. Helen's.
1881. D'Alton, Patrick Walter, Crohill, Angles Road, Streatham, London, S.W.
1866. Daniel, Edward Freer, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent; and 11 Needwood Street, Burton-on-Trent.
1866. Daniel, William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds; and Oxford House, Horsforth, Leeds.

1864. Darby, Charles E., Brymbo Iron Works, near Wrexham.
1879. Darling, William Littell, Manager of Steel Works, Dowlais Iron Works, Dowlais.
1878. Darwin, Horace, 66 Hills Road, Cambridge. (*Life Member.*)
1873. Davey, Henry, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds.
1865. Davidson, James, Royal Arsenal, Laboratory Department, Woolwich.
1881. Davidson, James, Engineering Works, Cumberland Street, Dunedin, Otago, New Zealand: (or care of Messrs. Buxton Davidson and Lees, 18A Basinghall Street, London, E.C.)
1881. Davies, Benjamin, Bleach Works, Adlington, near Chorley.
1880. Davies, Charles Merson, Locomotive Superintendent, Holkar and Sindia-Neemuch State Railway, Khandwa, India.
1874. Davis, Alfred, 5 Westminster Chambers, Victoria Street, Westminster, S.W.
1868. Davis, Henry Wheeler, 11 New Broad Street, London, E.C.
1873. Davis, John Henry, Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester; and 64 Cannon Street, London, E.C.
1877. Davison, John Walter, Messrs. William and John Davison, Engineers and Ironfounders, Moscow, Russia: (or care of Alfred L. Sacré, 60 Queen Victoria Street, London, E.C.)
1873. Davy, David, Messrs. Davy Brothers, Park Iron Works, Sheffield.
1874. Davy, Walter Scott, Messrs. Davy Brothers, Park Iron Works, Sheffield.
1874. Daw, Samuel, Pearston House, 23 The Walk, Tredegarville, Cardiff.
1849. Dawes, George, Milton and Elsecar Iron Works, near Barnsley.
1879. Dawson, Bernard, The Laurels, Malvern Link, Malvern.
1876. Dawson, Thomas Joseph, Mining Engineer, Cocken, near Fence Houses.
1869. Day, St. John Vincent, 115 St. Vincent Street, Glasgow.
1874. Deacon, George Frederick, Municipal Offices, Dale Street, Liverpool.
1880. Deacon, Richard William, Kalimaas Works, Sourabaya, Java.
1868. Dean, William, Locomotive Superintendent, Great Western Railway, Swindon.
1866. Death, Ephraim, Messrs. Death and Ellwood, Albert Works, Leicester.
1877. Dees, James Gibson, 36 King Street, Whitehaven.
1858. Dempsey, William, 26 Great George Street, Westminster, S.W.
1872. Denton, John Punshon, Tanton Hall, Stokesley, near Northallerton.
1880. De Pape, William Alfred Harry, Tottenham Board of Health, Coombes Croft House, High Road, Tottenham, Middlesex.
1868. Derham, John J., Brookside, near Blackburn.
1880. Dickinson, John, Palmer's Hill Engine Works, Sunderland.

1875. Dickinson, William, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.

1879. Dickson, John, Railway Wheel and Axle Works, Stourbridge.

1872. Dobson, Benjamin Alfred, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton.

1880. Dodd, John, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1868. Dodman, Alfred, Highgate Foundry, Lynn.

1880. Donald, James, Messrs. Fraser and Miller, Carnac Iron Works, Bombay.

1876. Donaldson, John, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W.; and Tower House, Turnham Green.

1873. Donkin, Bryan, Jun., Messrs. B. Donkin and Co., Blue Anchor Road, Bermondsey, London, S.E.

1877. Dossor, Arthur Loft, 33 Ladywell Park, Lewisham, Kent, S.E.

1865. Douglas, Charles Prattman, Consett Iron Works, near Blackhill, County Durham; and Consett House, Consett, County Durham.

1879. Douglass, James Nicholas, Engineer to the Trinity Board, Trinity House, London, E.C.

1879. Douglass, William, Chief Engineer to the Commissioners of Irish Lights, Westmoreland Street, Dublin.

1879. Doulton, Bernard, Lambeth Pottery, Lambeth, London, S.E.

1857. Dove, George, Messrs. Cowans Sheldon and Co., St. Nicholas Iron and Engine Works, Carlisle; and Viewfield, Stanwix, near Carlisle.

1873. Dove, George, Jun., Redbourn Hill Iron and Coal Works, Frodingham, near Brigg.

1866. Downey, Alfred C., Messrs. Downey and Co., Coatham Iron Works, Middlesbrough; and Post Office Chambers, Middlesbrough.

1881. Dowson, Joseph Emerson, 3 Great Queen Street, Westminster, S.W.

1880. Doxford, Robert Pile, Messrs. William Doxford and Sons, Pallion Shipbuilding and Engine Works, Sunderland.

1874. Dredge, James, 35 Bedford Street, Strand, London, W.C.

1877. Dübs, Charles Ralph, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1877. Dübs, Henry John Sillars, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1880. Duckham, Frederic Eliot, Engineer, Millwall Docks, London, E.

1881. Duckham, Heber, 35 Queen Victoria Street, London, E.C.

1879. Duncan, David John Russell, Messrs. Duncan Brothers, 32 Queen Victoria Street, London, E.C.

1870. Dunlop, James Wilkie, 22 Leadenhall Street, London, E.C.

1881. Dunn, Henry Woodham, Knysna, Cape Colony.

1865. Dyson, Robert, Messrs. Owen and Dyson, Rother Iron Works, Rotherham.

1880. Eager, John Edward, Messrs. William Crichton and Co., Engineering and Shipbuilding Works, Abo, Finland.

1869. Earnshaw, William Lawrence, Superintending Marine Engineer, South Eastern Railway, Folkestone.

1858. Easton, Edward, 9 Delahay Street, Westminster, S.W.

1867. Easton, James, Mining Engineer, Nest House, Gateshead.

1875. Eaves, William, Engineer, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield.

1878. Eckart, William Roberts, Messrs. Salkeld and Eckart, 632 Market Street, P. O. Box 1587, San Francisco, California, United States.

1868. Eddison, Robert William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1871. Edwards, Edgar James, Butterley Iron Works, Alfreton.

1877. Edwards, Frederick, Superintending Engineer, Weymouth and Channel Islands Steam Packet Co., &c., 127 Leadenhall Street, London, E.C.

1880. Edwards, Robert, 9 Launder Terrace, Grantham.

1866. Elce, John, 25 Cathedral Yard, Manchester.

1879. Ellacott, Robert Henry, Messrs. Ellacott and Sons, Plymouth Foundry, Plymouth.

1875. Ellington, Edward Bayzand, Hydraulic Engineering Works, Chester; and Hydraulic Engineering Co., Palace Chambers, 9 Bridge Street, Westminster, S.W.

1859. Elliot, Sir George, Bart., M.P., Houghton-le-Spring, near Fence Houses.

1869. Elliott, Henry Worton, Metal Sheathing Works, 10 Coleshill Street, Birmingham; and Selly Oak Works, near Birmingham.

1877. Elliott, Thomas Mark, Messrs. Robert Elliott and Sons, Pensher Foundry, Fence Houses.

1880. Ellis, Oswald William, 26 George Street, Edinburgh.

1870. Elsdon, Robert, 76 Manor Road, Upper New Cross, London, S.E.

1869. Elwell, Alfred, Edge Tool Works, Wood Green, Wednesbury.

1875. Elwell, Thomas, Messrs. Varrall Elwell and Middleton, 1 Avenue Trudaine, Paris.

1878. Elwin, Charles, Metropolitan Board of Works, Spring Gardens, London, S.W.

1864. Everitt, William Edward, Messrs. Allen Everitt and Sons, Kingston Metal Works, Adderley Street, Birmingham; and Finstal, Bromsgrove.

1881. Ewen, Thomas Buttwell, Messrs. Tangye Brothers, Cornwall Works, Soho, near Birmingham.

1869. Eyth, Max, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1869. Faija, Henry, 4 Great Queen Street, Westminster, S.W.

1868. Fairbairn, Sir Andrew, M.P., Wellington Foundry, Leeds; and 15 Portman Square, London, W.

1875. Farcot, Jean Joseph Léon, Messrs. Farcot and Sons, Engine Works 13 Avenue de la Gare, St. Ouen, France.

1880. Farcot, Paul, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1867. Fardon, Thomas, 63 Collingdon Street, Luton.

1881. Farrar, Sidney Howard, Messrs. Howard Farrar and Co., Port Elizabeth, South Africa; and 69 Cornhill, London, E.C.

1876. Fell, John Corry, 23 Rood Lane, Fenchurch Street, London, E.C.

1877. Fenton, James, Manager, Messrs. Kitson and Co., Airedale Foundry, Leeds.

1869. Fenwick, Clennell, Victoria Docks Engine Works, Victoria Docks, London, E.

1870. Ferguson, Henry Tanner, Locomotive Superintendent, Punjaub Northern State Railway, Rawal Pindi, Punjaub, India.

1881. Ferguson, William, Assistant Professor of Engineering, Dublin University, Dublin.

1854. Fernie, John, 12 King Henry's Road, London, N.W.

1866. Fiddes, Walter, Engineer, Bristol United Gas Works, Bristol.

1872. Fidler, Edward, Platt Lane Colliery, Wigan.

1867. Field, Edward, Messrs. Field Field and Cotton, Chandos Chambers, 22 Buckingham Street, Adelphi, London, W.C.

1861. Field, Joshua, 110 Westminster Bridge Road, Lambeth, London, S.E.

1874. Fielding, John, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester.

1865. Filliter, Edward, 16 East Parade, Leeds.

1874. Firth, William, Burley Wood, Leeds.

1871. Fisher, Benjamin Samuel, Locomotive Superintendent, Somerset and Dorset Railway, Highbridge, near Bridgwater.

1877. Flannery, James Fortescue, 9 Fenchurch Street, London, E.C.

1864. Fleet, Thomas, Crown Boiler and Gasholder Works, Westbromwich.

1847. Fletcher, Edward, Locomotive Superintendent, North Eastern Railway, Gateshead.

1858. Fletcher, Henry Allason, Messrs. Fletcher Jennings and Co., Lowca Engine Works, Whitehaven. (*Life Member.*)

1872. Fletcher, Herbert, Ladyshore Colliery, Little Lever, Bolton; and The Hollins, Bolton.

1857. Fletcher, James, Messrs. W. Collier and Co., Worsley Street, New Bailey Street, Salford, Manchester.

1867. Fletcher, Lavington Evans, Chief Engineer, Manchester Steam Users' Association, 9 Mount Street, Albert Square, Manchester.

1872. Flower, James J. A., Messrs. James Flower and Sons, Old Trinity House, 5 Water Lane, Great Tower Street, London, E.C.

1859. Fogg, Robert, 11 Queen Anne's Gate, Westminster, S.W.

1878. Fontaine, Marc Berrier-, Ingénieur de la Marine, Toulon Dockyard, Toulon, France.

1877. Forbes, Daniel Walker, Smithfield Works, New Road, Blackwall, London, E.

1861. Forster, Edward, Messrs. Chance Brothers and Co., Glass Works, Spon Lane, near Birmingham.

1877. Foulis, William, Engineer, Glasgow Corporation Gas Works, 42 Virginia Street, Glasgow.

1866. Fowler, George, Mining Engineer, Basford Hall, near Nottingham.

1847. Fowler, John, 2 Queen Square Place, Westminster, S.W.

1866. Fox, Charles Douglas, 5 Delahay Street, Westminster, S.W.

1875. Fox, Samson, Leeds Forge, Leeds.

1859. Fraser, John, 13 Park Square, Leeds.

1877. Fraser, John Hazell, Messrs. Fraser Brothers, Railway Iron Works, Bromley, London, E.

1876. Frost, William, Manager, Carlisle Steel and Engine Works, Sheffield; and Woodhill, Sheffield.

1866. Fry, Albert, Bristol Wagon Works, Temple Gate, Bristol.

1866. Galloway, Charles John, Messrs. W. and J. Galloway and Sons, Knott Mill Iron Works, Manchester.

1862. Galton, Capt. Douglas, C.B., R.E., F.R.S., 12 Chester Street, Grosvenor Place, London, S.W.

1880. Galwey, John Wilfrid de Villemont, Messrs. Galwey Whitehead and Co. Warrington Engine and Iron Works, Lythgoe's Lane, Warrington.

1867. Gauntlett, William Henry, 33 Albert Terrace, Middlesbrough.

1878. Geach, John Jabez, New Passage, near Bristol.

1880. Geoghegan, Samuel, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin.

1871. Gibbins, Richard Cadbury, Berkley Street, Birmingham.

1872. Gilbert, Ebenezer Edwin, Canada Engine Works, Montreal, Canada.

1856. Gilkes, Edgar, Tees Side Iron and Engine Works, Middlesbrough.

1880. Gill, Charles, Messrs. Young and Gill, Engineering Works, Java; and Java Lodge, Beckenham.

1866. Gilroy, George, Engineer, Ince Hall Colliery, Wigan.

1878. Gimson, Josiah, Welford Road Engine Works, Leicester.

1881. Girdwood, William Wallace, Indestructible Packing Works, East India Dock Road, Poplar, London, E.

1874. Gjers, John, Messrs. Gjers Mills and Co., Ayresome Iron Works, Middlesbrough.
1862. Godfrey, Samuel, Messrs. Bolckow Vaughan and Co., Iron Works, Middlesbrough.
1880. Godfrey, William Bernard, 54 Regent's Park Road, Regent's Park, London, N.W.
1879. Goldsworthy, Robert Bruce, Messrs. Thomas Goldsworthy and Sons, Britannia Emery Mills, Hulme, Manchester.
1867. Gooch, William Frederick, Vulcan Foundry, Warrington.
1877. Goodbody, Robert, Messrs. Goodbody, Clashawaun Jute Factory, Clara, near Moate, Ireland.
1869. Goodeve, Thomas Minchin, 5 Crown Office Row, Temple, London, E.C.
1875. Goodfellow, George Ben, Hyde Iron Works, Hyde, near Manchester.
1865. Göransson, Göran Fredrick, Sandvik Iron Works, near Gefle, Sweden.
1875. Gordon, Robert, Executive Engineer, Public Works Department, Henzada, British Burmah, India: (or care of Messrs. Henry S. King and Co., 45 Pall Mall, London, S.W.)
1879. Gorman, William Augustus, Messrs. Siebe and Gorman, 187 Westminster Bridge Road, London, S.E.
1880. Gottschalk, Alexandre, 17 Rue Laffitte, Paris.
1877. Goulty, Wallis Rivers, Albert Chambers, Albert Square, Manchester.
1871. Gowenlock, Alfred Hargreaves, Messrs. Jessop and Co., Railway Contractors, 93 Clive Street, Calcutta; and Phœnix House, Alleyne Park, West Dulwich, London, S.E.
1878. Grafton, Alexander, 15 Great George Street, Westminster, S.W.
1869. Grainger, James Nixon, Public Works Department, Chepank, Madras; and The Mall, Newport, Isle of Wight.
1865. Gray, John McFarlane, Chief Examiner of Engineers, Marine Department, Board of Trade; 35 Beresford Road, Highbury New Park, London, N.
1876. Gray, John William, Engineer, Corporation Water Works, Broad Street, Birmingham.
1870. Gray, Matthew, 106 Cannon Street, London, E.C.; and Silvertown Telegraph Works, North Woolwich, E.
1879. Gray, Thomas Lowe, Rokesley House, St. Michael's Road, Stockwell, London, S.W.
1879. Greathead, James Henry, 8 Victoria Chambers, Victoria Street, Westminster, S.W.
1861. Green, Edward, Messrs. E. Green and Son, Phœnix Works, Wakefield.
1871. Greener, John Henry, 14 St. Swithin's Lane, London, E.C.
1878. Greenwood, Arthur, Messrs. Greenwood and Batley, Albion Works, Leeds.
1874. Greenwood, William Henry, Messrs. Stacey Davis and Co., Phœnix Foundry and Engineering Works, Derby.

1865. Greig, David, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1880. Gresham, James, Messrs. Gresham and Craven, Craven Iron Works, Ordsal Lane, Salford, Manchester.

1874. Grew, Nathaniel, Dashwood House, 9 New Broad Street, London, E.C.

1866. Grice, Edwin James, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1860. Grice, Frederic Groom, Oakley Villa, Westbromwich.

1868. Grierson, Henry Houldsworth, Messrs. Ormerod Grierson and Co., St. George's Iron Works, Hulme, Manchester.

1873. Griffiths, John Alfred, Engineer, Waste Water Meter Co., 32 Park Lane, Liverpool; and 93 Wordsworth Street, Liverpool.

1879. Grose, Arthur, Manager, Vulcan Iron Works, Guildhall Road, Northampton.

1870. Guilford, Francis Leaver, Messrs. G. R. Cowen and Co., Beck Foundry Brook Street, Nottingham.

1870. Gwynne, James Eglinton Anderson, Essex Street Works, Strand, London, W.C. (*Life Member.*)

1870. Gwynne, John, Hammersmith Iron Works, Hammersmith, London, W.

1879. Hadfield, Robert, Hadfield Steel Foundry Co., Attercliffe, Sheffield.

1861. Haggie, Peter, Hemp and Wire Rope Works, Gateshead.

1879. Hall, John Francis, Messrs. W. Jessop and Sons, Brightside Steel Works, Sheffield.

1881. Hall, John Percy, Wallsend Slipway and Engineering Co., Wallsend, near Newcastle-on-Tyne.

1874. Hall, Thomas Bernard, Patent Nut and Bolt Works, Smethwick, near Birmingham; and Sunnyside, Sandon Road, Edgbaston, Birmingham.

1871. Hall, William Silver, Messrs. Hall and Clarke, Canal Street Iron Works, Derby; and 39 Hartington Street, Derby.

1880. Hallett, John Harry, 120 Powell's Place, Cardiff.

1871. Halpin, Druitt, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1870. Hamand, Arthur Samuel, 9 Bridge Street, Westminster, S.W.

1875. Hammond, Walter John, Resident Engineer and Locomotive Superintendent, Paulista Railway, Campinas, Sâo Paulo, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)

1879. Handyside, James Baird, Messrs. Thomson Sterne and Co., Crown Iron Works, Glasgow.

1870. Hannah, Joseph Edward, Abbeystead, Wyresdale, near Lancaster.

1874. Harding, William Bishop, IX. Bez., Uellöerstrasse Nr. 35, Budapest, Hungary.

1881. Hardingham, George Gatton Melhuish, 191 Fleet Street, London, E.C.
1869. Harfield, William Horatio, Mansion House Buildings, Queen Victoria Street, London, E.C.
1873. Harman, Harry Jones, Chief Engineer, English and Scottish Boiler Insurance Company, 100 King Street, Manchester.
1879. Harris, Henry Graham, 37 Great George Street, Westminster, S.W.
1873. Harris, Richard Henry, 63 Queen Victoria Street, London, E.C.
1877. Harris, William Wallington, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.; and 24 Alexandra Villas, Hornsey Park, London, N.
1879. Harrison, George, 1 Arthur's Grove, Leicester Street, Hull.
1871. Harrison, Joseph Edward, Woodside Iron Works, near Dudley.
1858. Harrison, Thomas Elliot, Engineer-in-Chief, North Eastern Railway, Newcastle-on-Tyne.
1865. Harrison, William Arthur, Messrs. Allen Harrison and Co., Cambridge Street Works, Manchester.
1874. Hart, James, Messrs. David Hart and Co., North London Iron Works, Wenlock Road, City Road, London, N.
1877. Hart, James, Borough Engineer and Surveyor, Town Hall, St. Helen's.
1872. Hartnell, Wilson, Park Row, Leeds.
1878. Harwood, Robert, Soho Iron Works, Bolton.
1881. Haslam, Alfred Seale, Union Foundry, Derby.
1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.
1857. Haughton, S. Wilfred, Greenbank, Carlow, Ireland. (*Life Member.*)
1878. Haughton, Thomas, 122 Cannon Street, London, E.C.
1861. Hawkins, William Bailey, 2 Suffolk Lane, Cannon Street, London, E.C.
1870. Hawksley, Charles, 30 Great George Street, Westminster, S.W.
1856. Hawksley, Thomas, F.R.S., 30 Great George Street, Westminster, S.W.
1873. Hay, James A. C., Superintendent of Machinery to the War Department, Royal Arsenal, Woolwich.
1879. Hayes, John, 27 Leadenhall Street, London, E.C.
1862. Haynes, Thomas John, Calpe Foundry and Forge, North Front, Gibraltar.
1880. Hayter, Harrison, 33 Great George Street, Westminster, S.W.
1869. Head, Jeremiah, Messrs. Fox Head and Co., Newport Rolling Mills, Middlesbrough.
1860. Head, John, Messrs. Ransomes Head and Jefferies, Orwell Works, Ipswich.
1873. Headly, Lawrance, 1 Camden Place, Cambridge.
1857. Healey, Edward Charles, 163 Strand, London, W.C.
1872. Heap, William, 9 Rumford Place, Liverpool.

1864. Heathfield, Richard, Lion Galvanising Works, Wiggin Street, Icknield Port Road, Birmingham.

1878. Hedges, Killingworth William, 25 Queen Anne's Gate, Westminster, S.W.

1875. Heenan, Richard Hammersley, Parsonstown, Ireland.

1879. Henchman, Humphrey, Cape Government Railways, Uitenhage, Cape of Good Hope: (or care of John Henchman, Uplands, Wallington, Surrey).

1869. Henderson, David Marr, Engineer-in-Chief, Imperial Maritime Customs Service of China, Shanghai, China; and Gattaway, Abernethy, Newburgh, Fife.

1878. Henesey, Richard, Superintending Engineer, Messrs. W. Nicol and Co., Byculla Iron Works, Bombay.

1879. Henriques, Cecil Quixam, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1875. Hepburn, George, Redcross Chambers, Redcross Street, Liverpool.

1876. Heppell, Thomas, Mining Engineer, Ouston Collieries, Chester-le-Street.

1877. Hepworth, Thomas Howard, Curzon House, Curzon Street, Derby.

1865. Hetherington, John Muir, Vulcan Works, Pollard Street, Manchester.

1866. Hetherington, Thomas Ridley, Vulcan Works, Pollard Street, Manchester.

1865. Hewett, Edward Edwards, High Court, High Street, Sheffield.

1872. Hewlett, Alfred, Haseley Manor, Warwick.

1872. Hewlett, William Henry, Wigan Coal and Iron Works, Kirkless Hall, Wigan.

1871. Hick, John, M.P., Mytton Hall, Whalley, near Blackburn.

1864. Hide, Thomas C., Messrs. Hide and Thompson, 4 Cullum Street, Fenchurch Street, London, E.C.

1879. Higson, Jacob, Mining Engineer, Crown Buildings, 18 Booth Street, Manchester.

1870. Higson, John, Mining Engineer, Crown Buildings, 18 Booth Street, Manchester.

1871. Hill, Alfred C., Clay Lane Iron Works, South Bank, Yorkshire.

1873. Hilton, Franklin, Messrs. Bolckow Vaughan and Co., Iron Works, Middlesbrough.

1876. Hind, Thomas William, Messrs. Henry Hind and Son, Central Engineering Tool Works, Queen's Road, Nottingham; and 62 Blackfriars Road, London, S.E.

1874. Hird, Holmes, Crane Villa, Upper Dale Road, New Normanton, Derby.

1870. Hodges, Petronius, 171 Burngreave Road, Sheffield.

1880. Hodgson, Charles, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W.

1852. Holcroft, James, Norton, near Stourbridge.

1866. Holcroft, Thomas, Bilston Foundry, Bilston.

1865. Holliday, John, Messrs. John Bethell and Co., Creosote Works, Westbromwich; and Oakfield Lodge, Booth Street, Handsworth, Birmingham.

1863. Holt, Francis, Midland Railway, Locomotive Department, Derby.

1873. Holt, Henry Percy, 15 Park Row, Leeds.

1867. Holt, William Lyster, 1 Pelham Place, South Kensington, London, S.W.

1867. Homer, Charles James, Mining Engineer, Stoke-upon-Trent.

1848. Homersham, Samuel Collett, 19 Buckingham Street, Adelphi, London, W.C.

1866. Hopkins, John Satchell, Jesmond Grove, Highfield Road, Edgbaston, Birmingham.

1856. Hopkinson, John, Grove House, Oxford Road, Manchester.

1874. Hopkinson, John, Jun., D.Sc., F.R.S., Lighthouse Department, Messrs. Chance Brothers and Co., Spon Lane, near Birmingham; and 4 Westminster Chambers, Victoria Street, Westminster, S.W.

1877. Hopkinson, Joseph, Messrs. Joseph Hopkinson and Co., Britannia Works, Huddersfield.

1867. Hopper, William, Machine Works, Moscow: (or care of Thomas Hopper, 46 Queen Street, Edinburgh.)

1880. Hornsby, James, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham.

1880. Hornsby, William, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham.

1873. Horsley, Charles, 22 Wharf Road, City Road, London, N.

1868. Horsley, Thomas, King's Newton, near Derby.

1858. Horsley, William, Whitehill Point Iron Works, Percy Main, near Newcastle-on-Tyne.

1868. Horton, Enoch, Alma Works, Darlaston, near Wednesbury.

1871. Horton, George, Messrs. Horton and Son, Steam Boiler Works, 63 Park Street, Southwark, London, S.E.

1875. Hosgood, Thomas Hopkin, Gadlys Tin Works, Aberdare; and Bute Villa, Aberdare.

1873. Hoskin, Richard, 1 East Parade, Sheffield.

1866. Houghton, John Campbell Arthur, Woodside Iron Works, near Dudley.

1864. Howard, Eliot, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1860. Howard, James, M.P., Messrs. J. and F. Howard, Britannia Iron Works, Bedford; and Clapham Park, Bedfordshire.

1867. Howard, Robert Luke, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1861. Howell, Joseph Bennett, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield.

1877. Howell, Samuel Earnshaw, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield.

1877. Howlett, Francis, Messrs. Henry Clayton Son and Howlett, Atlas Works, Woodfield Road, Harrow Road, London, W.

1867. Hughes, George Douglas, Queen's Foundry, London Road, Nottingham.

1873. Hughes, Henry, Falcon Iron Works, Loughborough.

1871. Hughes, Joseph, Messrs. Fletcher Jennings and Co., Lowca Engine Works, Whitehaven.

1864. Hulse, William Wilson, Whalley Chambers, 88 King Street, Manchester.

1880. Humphrys, James, Barrow Shipbuilding Works, Barrow-in-Furness.

1866. Humphrys, Robert Harry, Deptford Pier, London, S.E.

1859. Hunt, James P., Corngreaves Iron Works, near Birmingham.

1856. Hunt, Thomas, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1874. Hunt, William, Jun., Messrs. William Hunt and Sons, Alkali Works, Lea Brook, Wednesbury; and Aire and Calder Chemical Works, Castleford, near Normanton.

1877. Hunter, Walter, Messrs. Hunter and English, High Street, Bow, London, E.

1864. Hutchinson, Edward, Streonshalh House, Darlington.

1865. Hyde, Major-General Henry, R.E., India Office, Westminster, S.W. (*Life Member.*)

1877. Imray, John, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C.

1867. Inglis, William, Soho Iron Works, Bolton; and Astley Bridge, near Bolton.

1872. Inman, Charles Arthur, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead; and 45 North Corridor, The Albany, Liverpool.

1872. Jack, Alexander, Messrs. James Jack and Co., Victoria Engine Works, Boundary Street West, Vauxhall Road, Liverpool.

1876. Jackson, Henry James, Superintending Engineer, General Steam Navigation Co.'s Works, Deptford, London, S.E.

1859. Jackson, Matthew Murray, Engineer-in-Chief, Imperial Danube Steam Navigation Works, Budapest, Hungary.

1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester; and Blackbrooke, Grosmont, near Hereford.

1873. Jackson, Samuel, Locomotive and Carriage Superintendent, Great Indian Peninsula Railway, Bombay.

1872. Jackson, William Francis, Bowling Iron Works, near Bradford.

1873. Jacob, Edward Westley, Horseley Iron Works, Tipton.

1876. Jacobs, Charles Mattathias, Post Office Chambers, Bute Docks, Cardiff.

1878. Jakeman, Christopher John Wallace, Manager, Messrs. Merryweather and Sons, Tram Locomotive Works, Greenwich Road, London, S.E.

1877. James, Christopher, 4 Alexandra Road, Clifton, Bristol.

1856. James, Jabez, 40 Prince's Street, Commercial Road, Lambeth, London, S.E.

1877. James, John William Henry, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1879. Jameson, George, Glencormac, Bray, Ireland.

1881. Jameson, John, Messrs. Jameson and Schaeffer, Akenside Hill, Newcastle-on-Tyne.

1870. Jamieson, John Lennox Kincaid, 9 Crown Terrace, Dowanhill, Glasgow.

1876. Jebb, George Robert, Engineer to the Birmingham Canal Navigation Birmingham; and The Laurels, Shrewsbury.

1861. Jeffcock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.

1880. Jefferies, John Robert, Messrs. Ransomes Head and Jefferies, Orwell Works, Ipswich.

1881. Jefferiss, Thomas, Messrs. Tangye Brothers, Cornwall Works, Soho, near Birmingham.

1863. Jeffreys, Edward A., Monk Bridge Iron Works, Leeds; and Gipton Lodge, Leeds.

1876. Jemson, James, Engineer to the Kay Shuttleworth Mineral Estate, Gawthorpe Hall, near Burnley.

1875. Jenkin, H. C. Fleeming, F.R.S., Professor of Engineering, University of Edinburgh; 3 Great Stuart Street, Edinburgh.

1878. Jensen, Peter, Messrs. Brewer and Jensen, 33 Chancery Lane, London, W.C.

1878. Jessop, Joseph, London Steam Crane and Engine Works, Leicester.

1854. Jobson, John, Derwent Foundry, Derby.

1863. Johnson, Bryan, Hydraulic Engineering Works, Chester; and 34 King Street, Chester.

1861. Johnson, Samuel Waite, Locomotive Superintendent, Midland Railway, Derby.

1872. Joicey, Jacob Gowland, Messrs. J. and G. Joicey and Co., Forth Banks West Factory, Newcastle-on-Tyne.

1872. Jones, Charles, Messrs. John Jones and Sons, Marine Engine Works, William Street, Liverpool.

1871. Jones, Charles Henry, Assistant Locomotive Superintendent, Midland Railway, Derby.

1873. Jones, Edward, Anglo-American Brush Electric Light Co., Victoria Works, Vine Street, York Road, Lambeth, London, S.E.

1873. Jones, Edward Trygarn, Consulting Engineer to the Commercial Steam Ship Co., 32 Great St. Helen's, London, E.C.

1878. Jones, Frederick Robert, Superintendent of Nahan Iron Works, Nahan, Sirmoor State, near Umballa, Punjaub, India: (or care of Messrs. Richard W. Jones and Co., Newport, Monmouthshire.)

1867. Jones, George Edward, Adamwahan, Punjaub, India: (or care of Mrs. Edward Jones, Woodville, Wylde Green, near Birmingham.)

1878. Jones, Harry Edward, Engineer, Commercial Gas Works, Stepney, London, E.

1881. Jones, Herbert Edward, Locomotive Department, Midland Railway, Manchester.

1872. Jones, William Richard Sumption, Rajputana State Railway, Ajmeer, India: (or care of Messrs. Henry S. King and Co, 45 Pall Mall, London, S.W.)

1880. Joy, David, Barrow Shipbuilding Co., 112 Fenchurch Street, London, E.C.

1878. Jüngermann, Carl, Märkisch Schlesische Maschinenbau und Hütten Actien Gesellschaft, 3 Chaussée Strasse, Berlin.

1869. Keen, Arthur, Patent Nut and Bolt Works, Smethwick, near Birmingham.

1867. Kellett, John, Clayton Street, Wigan.

1873. Kelson, Frederick Colthurst, Greenbank, Waterloo, near Liverpool.

1881. Kendal, Ramsey, Locomotive Department, North Eastern Railway, Gateshead.

1863. Kennan, James, Agricultural Implement Works, 19 Fishamble Street, Dublin.

1879. Kennedy, Alexander Blackie William, Professor of Engineering, University College, Gower Street, London, W.C.

1847. Kennedy, James, Cressington Park, Aigburth, Liverpool.

1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway, 45 Finsbury Circus, London, E.C.; and 29 Lupus Street, St. George's Square, London, S.W.

1868. Kennedy, Thomas Stuart, Wellington Foundry, Leeds.

1875. Kenrick, George Hamilton, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich; and Maple Bank, Church Road, Edgbaston, Birmingham.

1866. Kershaw, John, 1 Arlington Street, Piccadilly, London, S.W.

1880. Kessler, Emil, Maschinenfabrik, Esslingen, Wurtemburg, Germany.

1872. King, William, Engineer, Liverpool United Gas Works, Duke Street, Liverpool.

1872. Kirk, Alexander Carnegie, Messrs. Robert Napier and Sons, Lancefield House, Glasgow; and Govan Park, Govan, Glasgow.

1877. Kirk, Henry, Messrs. Kirk Brothers and Co., New Yard Iron Works, Workington.

1875. Kirkwood, James, Chief Engineer, H.I.C.M. Ram Cruiser "Chao Jung": care of Commissioner of Customs, Shanghai, China.

1864. Kirtley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.W.

1859. Kitson, James, Jun., Monk Bridge Iron Works, Leeds.

1868. Kitson, John Hawthorn, Airedale Foundry, Leeds.

1874. Klein, Thorvald, Cliff Vale Wagon Works, Stoke-upon-Trent.

1875. Knight, John Henry, Weybourne House, Farnham.

1877. Kortright, Lawrence Moore, Superintendent of Public Works, St. Kitts, West Indies: (or care of G. D. Kortright, Plas Teg, near Mold, Flintshire.)

1881. Laing, Arthur, Deptford Shipbuilding Yard, Sunderland.

1872. Laird, Henry Hyndman, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.

1872. Laird, William, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.

1873. Lamb, William James, Newtown and Meadows Collieries, near Wigan.

1878. Lambourn, Thomas William, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich.

1863. Lancaster, John, Bilton Grange, Rugby.

1881. Langdon, William, Locomotive Superintendent and Chief Mechanical Engineer, Rio Tinto Railway and Mines, Huelva, Spain: (or care of William G. Parsons, 11 Queen Victoria Street, London, E.C.)

1881. Lange, Frederick Montague Townshend, Messrs. Lange's Wool-Combing Works, Saint Acheul-les-Amiens, Somme, France.

1877. Lange, Hermann Ludwig, Manager, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1879. Langley, Alfred Andrew, Engineer in Chief, Great Eastern Railway, Liverpool Street, London, E.C.

1879. Lapage, Richard Herbert, Locomotive Superintendent, Buenos Ayres and Campana Railway, Buenos Ayres: (or care of Clement Lapage, Nantwich).

1879. Larsen, Jorgen Daniel, 7 Poultry, London, E.C.; and 27 Dalhousie Square, Calcutta.

1881. Lavalley, Alexander, 48 Rue de Provence, Paris.

1867. Lawrence, Henry, The Grange Iron Works, Durham.

1874. Laws, William George, 5 Winchester Terrace, Newcastle-on-Tyne.

1870. Layborn, Daniel, Messrs. Caine and Layborn, Dutton Street, Liverpool.

1856. Laybourne, Richard, Isca Foundry, Newport, Monmouthshire.

1860. Lea, Henry, 38 Bennett's Hill, Birmingham.

1865. Ledger, Joseph, Keswick.

1862. Lee, J. C. Frank, 22 Great George Street, Westminster, S.W.

1871. Lee, William, Messrs. Lee Clerk and Robinson, Gospel Oak Iron Works, Tipton; and 110 Cannon Street, London, E.C.

1863. Lees, Samuel, Messrs. H. Lees and Sons, Park Bridge Iron Works, Ashton-under-Lyne.

1858. Leslie, Andrew, Iron Shipbuilding Yard, Hebburn, Newcastle-on-Tyne.

1878. Lewis, Gilbert, Manager, New Bridge Foundry, Adelphi Street, Salford, Manchester.

1872. Lewis, Richard Amelius, Messrs. John Spencer and Sons, Tyne Hæmatite Iron Works, Scotswood-on-Tyne.

1860. Lewis, Thomas William, Bute Mineral Estate Office, Aberdare; and Mardy, Aberdare.

1880. Lightfoot, Thomas Bell, 116 Fenchurch Street, London, E.C.; and 2 Granville Park, Blackheath, London, S.E.

1856. Linn, Alexander Grainger, 121 Upper Parliament Street, Liverpool.

1876. Lishman, Thomas, Mining Engineer, Hetton Colliery, near Fence Houses.

1881. List, John, Messrs. Easton and Anderson, Erith Iron Works, Erith, London, S.E.

1866. Little, George, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1867. Livesey, James, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1867. Lloyd, Charles, 167 Howard Place, Shelton, Stoke-upon-Trent.

1871. Lloyd, Francis Henry, Darlaston Steel and Iron Works, near Wednesbury; and Wood Green, Wednesbury.

1854. Lloyd, George Braithwaite, Messrs. Lloyds, High Street, Birmingham. (*Life Member.*)

1862. Lloyd, John, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire; and Priors Lee Hall, near Shifnal.

1864. Lloyd, Sampson Zachary, Areley Hall, Stourport.

1852. Lloyd, Samuel, The Farm, Sparkbrook, Birmingham.

1863. Loam, Matthew Hill, Gas and Water Engineer, Ivy House, Colwich Road, Nottingham.

1879. Lockhart, William Stronach, Fenchurch House, 7 Fenchurch Street, London, E.C.

1874. Logan, William, Mining Engineer, Langley Park Colliery, Durham.

1880. Longridge, Michael, Chief Engineer, Engine and Boiler Insurance Co., 12 King Street, Manchester.

1856. Longridge, Robert Bewick, Managing Director, Engine and Boiler Insurance Company, 12 King Street, Manchester; and Yew Tree House, Tabley, near Knutsford.

1875. Longridge, Robert Charles, Kilrie, Knutsford.
1880. Longworth, Daniel, 54 Bramah Road, Brixton Road, London, S.W.
1861. Low, George, Bishop's Hill Cottage, Ipswich.
1873. Lowe, John Edgar, Messrs. Bolling and Lowe, 2 Laurence Pountney Hill, London, E.C.
1873. Lucas, Arthur, 15 George Street, Hanover Square, London, W.
1877. Lupton, Arnold, Crossgates, near Leeds.
1878. Lüthy, Robert, Manager, Soho Iron Works, Bolton.
1854. Lynde, James Gascoigne, 32 St. Ann's Street, Manchester.
1878. Lynde, James Henry, 32 St. Ann's Street, Manchester.

1877. MacColl, Hector, Messrs. James Jack and Co., Victoria Engine Works, Boundary Street West, Vauxhall Road, Liverpool.
1879. Macdonald, Augustus VanZundt, Manager, Auckland Section, New Zealand Railways, Auckland, New Zealand.
1864. Macfarlane, Walter, Saracen Foundry, Possilpark, Glasgow.
1875. Maclagan, Robert, Chief Engineer, Imperial Mint, Osaka, Japan: (or care of Dr. Maclagan, 9 Cadogan Place, Belgrave Square, London, S.W.)
1877. MacLellan, John A., Messrs. Alley and MacLellan, 2 Peel Street, London Road, Glasgow.
1864. Macnab, Archibald Francis, Japanese Government Service, Yokohama, Japan; and 2 Cyprus Villas, Sutton Grove, Sutton, Surrey.
1865. MacNay, William, Shildon Engine Works, Darlington.
1865. Macnee, Daniel, 2 Westminster Chambers, Victoria Street, Westminster, S.W.; and Rotherham.
1878. Madge, Henry James, Engineer Inspector of Steam Boilers, 19 Lall-Bazar Street, Calcutta.
1879. Maginnis, James Porter, 10 Victoria Chambers, Victoria Street, Westminster, S.W.
1873. Mair, John George, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.
1879. Malcolm, Bowman, Locomotive Superintendent, Belfast and Northern Counties Railway, Belfast.
1881. Mallory, George Benjâmin, 55 Broadway, New York.
1876. Manlove, William Melland, Messrs. S. Manlove and Sons, Holy Moor Sewing-Cotton Spinning Mills, near Chesterfield.
1862. Mansell, Richard Christopher, Mechanical Engineer, South Eastern Railway, Ashford.
1875. Mansergh, James, 3 Westminster Chambers, Victoria Street, Westminster, S.W.
1862. Mappin, Frederick Thorpe, M.P., Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield; and Thornbury, Sheffield.

1857. March, George, Messrs. Maclea and March, Union Foundry, Dewsbury Road, Leeds.

1878. Marié, George, Engineer, Chemins de fer de Paris à Lyon et à la Méditerranée, Bureaux du Matériel, Boulevart Mazas, Paris.

1856. Markham, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield; and Tapton House, Chesterfield.

1871. Marsh, Henry William, Winterbourne, near Bristol.

1875. Marshall, Alfred, Perseverance Iron Works, Heneage Street, Whitechapel, London, E.; and Laurel Bank, Prospect Hill, Walthamstow, Essex. (*Life Member.*)

1865. Marshall, Francis Carr, Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.

1871. Marshall, James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.

1877. Marshall, William Bayley, General Manager, Staffordshire Wheel and Axle Works, Birmingham; and 15 Augustus Road, Birmingham.

1847. Marshall, William Prime, 15 Augustus Road, Birmingham.

1859. Marten, Edward Bindon, Chief Engineer, Midland Steam Boiler Inspection and Assurance Company, 56 Hagley Street, Stourbridge.

1853. Marten, Henry John, The Birches, Codsall, near Wolverhampton; and 4 Storey's Gate, Westminster, S.W.

1881. Martin, Edward Pritchard, Blaenavon Iron Works, Blaenavon, near Pontypool.

1878. Martin, Henry, Hanwell, Middlesex, W.

1880. Martin, Robert Frewen, Mount Sorrel Granite Co., Loughborough.

1854. Martineau, Francis Edgar, Globe Works, 278 New Town Row, Birmingham.

1880. Massicks, Thomas, Millom Iron Works, Millom, Cumberland.

1876. Mather, John, London and South Western Railway, Locomotive Department, Nine Elms, London, S.W.

1867. Mather, William, Messrs. Mather and Platt, Salford Iron Works, Manchester.

1875. Matthews, James, 46 Victoria Street, Bristol.

1875. Matthews, Thomas William, 6 Church Road, Heaton Norris, Stockport.

1875. Mattos, Antonio Gomes de, Messrs. Maylor and Co., Engineering Works, 136 Rua da Sande, Rio de Janeiro, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)

1853. Maudslay, Henry, Westminster Palace Hotel, Victoria Street, Westminster, S.W.: (or care of John Barnard, 47 Lincoln's Inn Fields, London, W.C.) (*Life Member.*)

1869. Maughan, Thomas, Engineer, Cramlington Colliery, Cramlington, Northumberland.

1873. Maw, William Henry, 35 Bedford Street, Strand, London, W.C.

1861. May, Robert Charles, 6 Great George Street, Westminster, S.W.

1865. Maylor, John, Churton Lodge, Churton, near Chester.

1859. Maylor, William, Ravenstone House, Farquhar Road, Upper Norwood, London, S.E. : (or care of Messrs. Stanes Watson and Co., 4 Cullum Street, Fenchurch Street, London, E.C.)

1874. McClean, Frank, 23 Great George Street, Westminster, S.W.

1872. McConnochie, John, Engineer to the Bute Harbour Trust, New Works, Bute Docks, Cardiff.

1878. McDonald, John Alexander, 4 Chapel Street, Cripplegate, London, E.C.

1865. McDonnell, Alexander, Locomotive Superintendent, Great Southern and Western Railway, Dublin.

1881. McGregor, Josiah, Crown Buildings, 78 Queen Victoria Street, London, E.C.

1868. McKay, Benjamin, Ice Works, Rockhampton, Queensland: (or care of Messrs. Lear Phillips and Co., 38 Dean Street, Birmingham).

1881. McKay, John, Messrs. R. and W. Hawthorn, St. Peter's Works, Newcastle-on-Tyne.

1880. McLachlan, John, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley.

1879. McLean, William Leckie Ewing, Lancefield Forge Co., Glasgow.

1863. Meek, Sturges, Resident Engineer, Lancashire and Yorkshire Railway, Manchester.

1881. Meik, Charles Scott, 6 York Place, Edinburgh.

1858. Meik, Thomas, 6 York Place, Edinburgh.

1857. Menelaus, William, Dowlais Iron Works, Dowlais.

1878. Menier, Henri, 37 Rue Ste. Croix de la Bretonnerie, Paris.

1876. Menzies, William, Messrs. Menzies and Blagburn, 9 Dean Street, Newcastle-on-Tyne.

1877. Merryweather, Henry, Messrs. Merryweather and Sons, Steam Fire-Engine Works, Greenwich Road, London, S.E.

1875. Merryweather, James Compton, Messrs. Merryweather and Sons, Fire-Engine Works, 63 Long Acre, London, W.C.

1881. Meysey-Thompson, Arthur Herbert, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds.

1877. Michele, Vitale Domenico de, 14 Delahay Street, Westminster, S.W.

1862. Miers, Francis C., Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.; and Eden Cottage, West Wickham Road, Beckenham.

1864. Miers, John William, 74 Addison Road, Kensington, London, W.

1874. Milburn, John, Hawkshead Foundry, Quay Side, Workington.

1856. Mitchell, Charles, Iron Shipbuilding Yard, Low Walker, Newcastle-on-Tyne.

1870. Moberly, Charles Henry, Messrs. Easton and Anderson, Erith Iron Works, Erith, London, S.E.

1879. Moffat, Thomas, Mining Engineer, Montreal Iron Ore Mines, Whitehaven.

1879. Molesworth, Guilford Lindsay, Consulting Engineer to the Government of India for State Railways, Supreme Government, India.

1881. Molinos, Léon, 48 Rue de Provence, Paris.

1872. Moon, Richard, Jun., Penyvoel, Llanymynech, Montgomeryshire.

1876. Moore, Joseph, Risdon Iron and Locomotive Works, San Francisco, California: (or care of Ralph Moore, Government Inspector of Mines Rutherglen, Glasgow.)

1872. Moorsom, Warren Maude, Linden Lodge, Clevedon.

1880. Moreland, Richard, Jun., Messrs. Richard Moreland and Son, 3 Old Street, St. Luke's, London, E.C.

1867. Morgans, Thomas, The Guildhall, Bristol.

1874. Morris, Edmund Legh, New River Water Works, Finsbury Park, London, N.

1880. Morris, Edward Russell, Messrs. Charles Powis, Carter, and Morris, Cyclops Works, Millwall Pier, London, E.; and 1 Heath Mount, Hampstead, London, N.W.

1868. Morris, William, Waldridge Colliery, Chester-le-Street.

1865. Mosse, James Robert, General Director of Ceylon Railways, Dimbula, Ceylon.

1858. Mountain, Charles George, Eagle Foundry, Broad Street, Birmingham.

1873. Muir, Alfred, Messrs. William Muir and Co., Britannia Works, Sherborne Street, Strangeways, Manchester.

1873. Muir, Edwin, 26 King Street, Manchester.

1863. Muir, William, 2 Walbrook, London, E.C.; and 16 Clyde Terrace, Brockley Road, New Cross, London, S.E.

1876. Muirhead, Richard, Messrs. Drake and Muirhead, Maidstone.

1865. Murdock, William Mallabey, Sun Foundry, Dewsbury Road, Leeds.

1881. Musgrave, James, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton.

1863. Musgrave, John, Globe Iron Works, Bolton.

1870. Napier, James Murdoch, Messrs. David Napier and Son, Vine Street, York Road, Lambeth, London, S.E.

1848. Napier, John, 23 Portman Square, London, W.

1861. Naylor, John William, Wellington Foundry, Leeds.

1863. Neilson, Walter Montgomerie, Hyde Park Locomotive Works, Glasgow; and Queen's Hill, Ringford, Kirkcudbrightshire.

1869. Nelson, James, Marine and Stationary Engine Works, Gateshead.

1881. Nesfield, Arthur, 7 Rumford Street, Liverpool.

1860. Nettlefold, Joseph Henry, Screw Works, Broad Street, Birmingham.

1879. Neville, Robert, Butleigh Court, Glastonbury.
1879. Newall, Robert Stirling, F.R.S., Wire Rope Works, Gateshead; and Ferndene, Gateshead.
1866. Newdigate, Albert Lewis, 25 Craven Street, Charing Cross, London, W.C. (*Life Member.*)
1881. Newman, Frederick, 5 Copthall Buildings, London, E.C.
1881. Nichol, Bryce Gray, Messrs. Donkin and Nichol, St. Andrew's Iron Works, Newcastle-on-Tyne.
1877. Nicolson, Donald, New Zealand Chambers, 34 Leadenhall Street, London, E.C.
1866. Norfolk, Richard, Beverley.
1868. Norris, William Gregory, Coalbrookdale Iron Works, Coalbrookdale, Shropshire.
1869. North, Frederic William, Mining Engineer, Rowley Hall, near Dudley.
1878. Northcott, William Henry, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E.; and 125 Queen's Road, Peckham, London, S.E.

1868. O'Connor, Charles, Mersey Steel and Iron Works, Caryl Street, Liverpool.
1875. Okes, John Charles Raymond, 39 Queen Victoria Street, London, E.C.
1880. Oldham, Robert Augustus, care of Messrs. Oldham Brothers, 110 Cannon Street, London, E.C.
1866. Oliver, William, Victoria and Broad Oaks Iron Works, Chesterfield.
1880. Ormiston, Thomas, Consulting Engineer to the Bombay Port Trust, Ormidale, Thurlow Park Road, West Dulwich, London, S.E.
1870. Osborn, Samuel, Clyde Steel and Iron Works, Sheffield.
1867. Oughterson, George Blake, care of Peter Brotherhood, 56 Compton Street, Goswell Road, London, E.C.
1847. Owen, William, Wheathill Foundry, Rotherham; and Clifton House, Rotherham.

1868. Paget, Arthur, Machine Works, Loughborough.
1881. Palmer, Cecil Brooke, Stanton Iron Works, Nottingham.
1877. Panton, William Henry, General Manager, Stockton Forge, Stockton-on-Tees.
1877. Park, John Carter, Locomotive Engineer, North London Railway, Bow, London, E.
1871. Parke, Frederick, Withnell Fire Clay Works, near Chorley.
1872. Parker, Thomas, Carriage Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.
1879. Parker, William, Chief Engineer Surveyor, Lloyd's Register, 2 White Lion Court, Cornhill, London, E.C.

1871. Parkes, Pershouse, 25 Exchange Buildings, Birmingham.

1881. Parry, Henry, 2 Side, Newcastle-on-Tyne.

1878. Parsons, The Hon. Richard Clere, Airedale Foundry, Leeds.

1877. Paton, John McClure Caldwell, Sourabaya, Java: (or care of Messrs. Manlove Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham.)

1881. Patterson, Anthony, Messrs. Salmon Barnes and Co., Canal Head Foundry and Engineering Works, Ulverston.

1881. Pattinson, John, Locomotive Superintendent, Riazan and Kosloff Railway, Kosloff, Russia.

1872. Paxman, James Noah, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester.

1880. Peache, James Courthope, London and North Western Railway, Locomotive Department, Crewe.

1869. Peacock, Ralph, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1869. Peacock, Ralph, Aire and Calder Foundry, Goole.

1847. Peacock, Richard, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester; and Gorton Hall, Gorton, near Manchester.

1874. Peaker, George, Engineer to the Small Arms Ammunition Factory, Kirkee, India.

1879. Pearce, George Cope, 2 St. Helen's Crescent, Swansea.

1873. Pearce, Richard, Deputy Carriage and Wagon Superintendent, East Indian Railway, Howrah, Bengal, India: (or care of W. J. Titley, 57 Lincoln's Inn Fields, London, W.C.)

1867. Pearce, Robert Webb, Carriage Superintendent, East Indian Railway, Howrah, Bengal, India; and 34 Russell Road, Kensington, London, W.

1873. Penn, John, Messrs. John Penn and Sons, Marine Engineers, Greenwich, S.E.

1873. Penn, William, Messrs. John Penn and Sons, Marine Engineers, Greenwich, S.E.

1874. Percy, Cornelius McLeod, King Street, Wigan.

1861. Perkins, Loftus, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.

1879. Perkins, Stanhope, Assistant Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, Manchester.

1863. Perry, Thomas J., Highfields Engine Works, Bilston.

1865. Perry, William, Claremont Place, Wednesbury.

1881. Philipson, John, Messrs. Atkinson and Philipson, Carriage Manufactory, 15 Pilgrim Street, Newcastle-on-Tyne.

1878. Phillips, John, Manager, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.; and 84 Blackfriars Road, London, S.E.

1876. Piercy, Henry James Taylor, Messrs. Piercy and Co., Broad Street Engine Works, Birmingham.

1877. Pigot, Thomas Francis, Professor of Engineering, Royal College of Science for Ireland, Dublin.

1876. Pinel, Charles Louis, Messrs. Lethuillier and Pinel, 26 Rue Meridienne, Rouen, France.

1879. Pitt, Robert, Messrs. Stothert and Pitt, Newark Foundry, Bath.

1878. Pitts, George Albert, care of Messrs. J. and W. Pitts, St. John's, Newfoundland; and care of T. A. Readwin, 8 Bloomsbury Square, London, W.C.

1871. Platt, James, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester.

1867. Platt, Samuel Radcliffe, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1878. Platts, John Joseph, Avonside Engine Works, Bristol; and 8 Albion Villas, Sydenham Park, London, S.E.

1869. Player, John, Clydach Foundry, near Swansea.

1876. Pollock, Julius Frederick Moore, Messrs. Pollock and Pollock, Longclose Works, Newtown, Leeds.

1876. Pooley, Henry, Messrs. Henry Pooley and Son, Albion Foundry, Liverpool.

1869. Potter, William Aubone, Mining Engineer, Cramlington House, Cramlington, Northumberland.

1864. Potts, Benjamin Langford Foster, 174 Camberwell Grove, London, S.E.

1851. Potts, John Thorpe, Messrs. Richmond and Potts, 119 South Fourth Street, Philadelphia, Pennsylvania, United States.

1878. Powell, Henry Coke, Messrs. Bartrum Powell and Co., 35 Queen Victoria Street, London, E.C.: (or care of C. M. Roffe, 1 Bedford Row, London, W.C.)

1870. Powell, Thomas (Son), Messrs. Thomas and T. Powell, 23 Rue St. Julien, Rouen, France.

1874. Powell, Thomas (Nephew), Brynhyfryd, Neath.

1867. Powell, William, Carleton, Pontefract.

1867. Pratchitt, John, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1865. Pratchitt, William, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1856. Preston, Francis, Turnbridge Iron Works and Forge, Huddersfield; and Netherfield House, Kirkburton, near Huddersfield.

1877. Price, Henry Sherley, Albert Chambers, Albert Square, Manchester.

1866. Price, John, General Manager, Messrs. Palmer's Shipbuilding and Iron Works, Jarrow; and Rose Villa, Gateshead Road, Jarrow.

1875. Prior, Johannes Andreas, 33 Bredgade, Copenhagen.

1874. Prosser, William Henry, Messrs. Harfield and Co., Mansion House Buildings, Queen Victoria Street, London, E.C.

1875. Provis, George Stanton, Whitehall Club, Parliament Street, Westminster, S.W.

1866. Putnam, William, Darlington Forge, Darlington.

1878. Quillacq, Augustus de, Société anonyme de Constructions mécaniques d'Anzin, Anzin (Nord), France.

1873. Radcliffe, Arthur Henry Wright, 5 Carr's Lane, Birmingham.

1870. Radcliffe, William, Camden House, 25 Collegiate Crescent, Sheffield.

1878. Radford, Richard Heber, 15 St. James' Row, Sheffield.

1868. Rafarel, Frederic William, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1878. Rait, Henry Milnes, Messrs. Rait and Lindsay, Cranstonhill Foundry, Glasgow; and 155 Fenchurch Street, London, E.C.

1847. Ramsbottom, John, Fernhill, Alderley Edge, Cheshire.

1866. Ramsden, Sir James, Abbot's Wood, Barrow-in-Furness.

1878. Ramsden, Robert, 177 Kingsland Road, London, E.

1860. Ransome, Allen, 304 King's Road, Chelsea, London, S.W.

1869. Ransome, Robert Charles, Messrs. Ransomes Head and Jefferies, Orwell Works, Ipswich.

1862. Ransome, Robert James, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich.

1873. Rapier, Richard Christopher, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich; and 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1867. Ratliffe, George, Mersey Steel and Iron Works, Caryl Street, Liverpool.

1862. Ravenhill, John R., 27 Courtfield Gardens, South Kensington, London, S.W

1872. Rawlins, John, Manager, Metropolitan Railway Carriage and Wagon Works, Saltley, Birmingham.

1878. Rawlinson, Robert, C.B., Chief Inspector, Local Government Board, Whitehall, London, S.W.

1881. Redpath, Francis Robert, Canada Sugar Refinery, Montreal, Canada.

1881. Reed, Charles Holloway, Trimdon Iron Works, Sunderland.

1870. Reed, Sir Edward James, K.C.B., M.P., F.R.S., Broadway Chambers, Westminster, S.W.

1859. Rennie, George Banks, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.; and 20 Lowndes Street, Lowndes Square, London, S.W.

1878. Rennie, John, care of H. T. Lannigan, 39 Upper Thames Street, London, E.C.

1879. Rennie, John Keith, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.

1881. Rennoldson, Joseph Middleton, Marine Engine Works, South Shields.

1876. Restler, James William, Assistant Engineer, Southwark and Vauxhall Water Works, Sumner Street, Southwark, London, S.E.

1862. Reynolds, Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1879. Reynolds, George Bernard, Assistant Manager, Warda Coal State Railway, Warora, Central Provinces, India: (or care of Messrs. Stilwell, 22 Arundel Street, Strand, London, W.C.)

1875. Rich, William Edmund, Engineer, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.

1866. Richards, Edward Windsor, Messrs. Bolckow Vaughan and Co., Iron Works, Middlesbrough.

1856. Richards, Josiah, Pontypool Iron and Tinplate Works, Pontypool.

1863. Richardson, The Hon. Edward, C.M.G., Minister of Public Works, Christchurch, Canterbury, New Zealand.

1881. Richardson, George, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1865. Richardson, John, Methley Park, near Leeds.

1873. Richardson, John, Engineer to Messrs. Robey and Co., Perseverance Iron Works, Lincoln.

1859. Richardson, William, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1874. Riches, Tom Hurry, Locomotive Superintendent, Taff Vale Railway, Cardiff.

1873. Rickaby, Alfred Austin, Bloomfield Engine Works, Sunderland.

1879. Ridley, James Cartmell, Queen Street, Newcastle-on-Tyne.

1863. Rigby, Samuel, Messrs. Armitage and Rigbys, Cock Hedge Mill, Warrington.

1874. Riley, James, General Manager, Steel Company of Scotland, 150 Hope Street, Glasgow.

1879. Rixom, Alfred John, Woodstone Steam Brick and Tile Works, Peterborough; and 38 The Grove, Hammersmith, London, W.

1879. Roberts, Thomas Herbert, Assistant Mechanical Superintendent, Grand Trunk Railway, Brockville, Ontario, Canada.

1879. Robertson, Duncan, Principal Surveyor for Scotland, Underwriters' Registry for Iron Vessels, 30 Gordon Street, Glasgow.

1848. Robertson, Henry, M.P., Great Western Railway, Shrewsbury; and 13 Lancaster Gate, London, W.; and Palé, Corwen.

1879. Robertson, William, Messrs. Boyd and Co., Engineers and Shipbuilders, Shanghai, China: (or care of Andrew Bruce, 46 Queen Victoria Street, London, E.C.)

1874. Robinson, Henry, 7 Westminster Chambers, Victoria Street, Westminster, S.W.

1876. Robinson, James Salkeld, Messrs. Thomas Robinson and Son, Rochdale.

1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester; and Westwood Hall, Leek, near Stoke-upon-Trent.

1878. Robinson, John Frederick, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.

1878. Robinson, Thomas Neild, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.

1866. Robson, Thomas, Mining Engineer, Lumley Thicks, Fence Houses.

1879. Rodger, William, 9 Forbes Street, Bombay.

1872. Rofe, Henry, Cavendish Hill, Sherwood, Nottingham.

1868. Rogers, William, East London and Queenstown Railway, Queenstown, Cape of Good Hope: (or care of J. Kenyon Rogers, 25 Water Street, Liverpool.)

1871. Rollo, David, Messrs. David Rollo and Sons, Fulton Engine Works, 10 Fulton Street, Liverpool.

1867. Rose, Henry Fullwood, Albert Iron Works, Moxley, near Wednesbury.

1867. Rose, Thomas, Machine Works, 37 Victoria Street, Manchester.

1874. Ross, John Alexander George, 34 Collingwood Street, Newcastle-on-Tyne.

1881. Ross, William, Messrs. Ross and Walpole, North Wall Iron Works, Dublin.

1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Peterborough.

1878. Routh, William Pole, 25 Rua de S. Francisco, Oporto, Portugal: (or care of Cyril E. Routh, 30 Jewry Street, Crutched Friars, London, E.C.)

1880. Routledge, Thomas, Ford Paper Works, Sunderland; and Claxheugh, Sunderland.

1860. Rumble, Thomas William, F.R.S.E., Chief Engineer, Southwark and Vauxhall Water Works, Sumner Street, Southwark, London, S.E. (*Life Member.*)

1878. Russell, The Hon. William, George Town, Demerara; and 65 Holland Park, London, W.

1867. Ruston, Joseph, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln.

1877. Rutter, Edward, Messrs. Seaward and Co., Canal Iron Works, Millwall, London, E.

1866. Ryland, Frederick, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich.

1866. Sacré, Alfred Louis, 60 Queen Victoria Street, London, E.C.

1859. Sacré, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Manchester.

1868. Sacré, Edward Antoine, 26 Parliament Street, Westminster, S.W.

1864. Said, Colonel M., Pasha, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 22 Great George Street, Westminster, S.W.)

1859. Salt, George, Sir Titus Salt, Bart., Sons and Co., Saltaire, near Bradford; and 33 St. James' Square, London, S.W.

1874. Sampson, James Lyons, Messrs. David Hart and Co., North London Iron Works, Wenlock Road, City Road, London, N.

1864. Samuda, Joseph D'Aguilar, Iron Ship Building Yard, Isle of Dogs, Poplar, London, E.

1865. Samuelson, Bernhard, M.P., F.R.S., Britannia Iron Works, Banbury; and 56 Prince's Gate, South Kensington, London, S.W.; and Lupton, Brixham, South Devon.

1881. Samuelson, Ernest, Messrs. Samuelson and Co., Britannia Iron Works, Banbury.

1881. Sanders, Henry Conrad, Messrs. H. G. Sanders and Son, Wharf Road, Latimer Road, London, W.; and 7 Boscombe Road, Shepherd's Bush, London, W.

1871. Sanders, Richard David, St. Andrew's, Clarendon Road, Southsea, Portsmouth.

1881. Sandiford, Charles, Locomotive Superintendent, Scinde Punjaub and Delhi Railway, Lahore, India.

1874. Sauvée, Albert, 22 Parliament Street, Westminster, S.W.

1880. Saxby, John, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W.

1869. Scarlett, James, Messrs. E. Green and Son, 14 St. Ann's Square, Manchester.

1880. Schram, Richard, 9 Northumberland Street, Strand, London, W.C.

1876. Scott, David, Bengal Club, Calcutta.

1875. Scott, Frederick Whitaker, Atlas Steel and Iron Wire Rope Works, Reddish, Stockport.

1881. Scott, George Innes, 4 Queen Street, Newcastle-on-Tyne.

1877. Scott, Irving M., Messrs. Prescott Scott and Co., Union Iron Works, San Francisco, California.

1881. Scott, James, Despatch Wool-Washing Co., Port Elizabeth, Algoa Bay, Cape Colony: (or care of Mr. Wallace, The Home Farm, Murthly, Perthshire.)

1861. Scott, Walter Henry, Park Road, East Molesey, Kingston-on-Thames.

1868. Scriven, Charles, Messrs. Scriven and Holdsworth, Leeds Old Foundry, Marsh Lane, Leeds.

1864. Seddon, John, 98 Wallgate, Wigan.

1873. Seddon, John Frederick, Mining Engineer, Great Harwood Collieries, near Accrington.

1857. Selby, George Thomas, Smethwick Tube Works, Birmingham.

1865. Sellers, William, Pennsylvania Avenue, Philadelphia, Pennsylvania, United States.

1881. Sennett, Richard, Devonport Dockyard, Devonport.

1872. Shanks, Arthur, Messrs. A. Burn and Co., Engineers and Contractors, 7 Hastings Street, Calcutta.

1881. Shanks, William Weallens, 18 Strand Road, Howrah, Bengal.

1881. Shapton, William, Sir William G. Armstrong and Co., 8 Great George Street, Westminster, S.W.

1863. Sharp, Henry, Bolton Iron and Steel Works, Bolton.

1875. Sharp, Thomas Budworth, Managing Engineer, Muntz Metal Works, Birmingham.

1867. Sharpe, Charles James, 27 Great George Street, Westminster, S.W.

1869. Sharrock, Samuel, Windsor Iron Works, Garston, near Liverpool; and 8 Old Jewry, London, E.C.

1864. Shaw, Duncan, Mining Engineer, Cordoba, Spain.

1879. Shaw, Henry Selby Hele, Assistant to Professor of Engineering, University College, Bristol.

1881. Shaw, Joshua, Messrs. John Shaw and Sons, Wellington Street Works, Salford, Manchester.

1881. Shaw, William, Jun., Stanners Closes Steel Works, Wolsingham, near Darlington.

1856. Shelley, Charles Percy Bysshe, 45 Parliament Street, Westminster, S.W.

1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.

1876. Shield, Henry, Messrs. Fawcett Preston and Co., Phœnix Foundry, 17 York Street, Liverpool.

1872. Shoolbred, James Nelson, 3 Westminster Chambers, Victoria Street, Westminster, S.W.

1859. Shuttleworth, Joseph, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.

1851. Siemens, Charles William, D.C.L., LL.D., F.R.S., 12 Queen Anne's Gate, Westminster, S.W.; and 3 Palace Houses, Bayswater Road, London, W.

1871. Simon, Henry, 7 St. Peter's Square, Manchester.

1877. Simonds, William Turner, Messrs. J. C. Simonds and Son, Oil Mills, Boston. (*Life Member.*)

1873. Simpson, Alfred, 11 High Street, Hull; and Denmark House, Alexandra Road, St. John's Wood, near Hull.

1876. Simpson, Arthur Telford, Engineer, Chelsea Water Works, 35 Commercial Road, Pimlico, London, S.W.

1878. Simpson, James, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.

1847. Sinclair, Robert, care of Messrs. Sinclair Hamilton and Co., 17 St. Helen's Place, Bishopsgate Street, London, E.C.

1857. Sinclair, Robert Cooper, 3 Adelaide Place, London Bridge, London, E.C.

1881. Sisson, William, Messrs. Cox and Co., Falmouth Docks Engine and Shipbuilding Works, Falmouth.

1872. Slater, Alfred, Gloucester Wagon Works, Gloucester.

1859. Slater, Isaac, Gloucester Wagon Works, Gloucester.

1853. Slaughter, Edward, 4 Clifton Park, Clifton, Bristol.

1879. Smith, Allison Dalrymple, Locomotive Superintendent, Canterbury Railways, Christchurch, New Zealand.

1873. Smith, Charles, Manager, Messrs. Thomas Richardson and Sons, Hartlepool Iron Works, Hartlepool.

1879. Smith, Charles Hubert, Engineer and Shipwright Surveyor to the Board of Trade, St. Katharine Dock House, Tower Hill, London, E.

1866. Smith, Edward Fisher, The Priory Offices, Dudley.

1866. Smith, George Fereday, Grovehurst, Tunbridge Wells.

1860. Smith, Henry, Messrs. Hill and Smith, Brierley Hill Iron Works, Brierley Hill.

1881. Smith, Henry, Messrs. Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.

1860. Smith, John, Brass Foundry, Traffic Street, Derby.

1876. Smith, John, Messrs. Thomas Robinson and Son, Rochdale.

1857. Smith, Josiah Timmis, Hæmatite Iron and Steel Works, Barrow-in-Furness.

1870. Smith, Michael Holroyd, Royal Insurance Buildings, Crossley Street, Halifax.

1881. Smith, Robert Henry, Professor of Engineering, Sir Josiah Mason's Science College, Birmingham.

1881. Smith, Wasteneys, 59 Sandhill, Newcastle-on-Tyne.

1866. Smith, William, Messrs. William Smith and Sons, Partick Engine Works, Glasgow.

1863. Smith, William Ford, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester.

1859. Sokoloff, Major-General Alexander, Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt, Russia: (or care of Messrs. W. Collier and Co., Worsley Street, New Bailey Street, Salford, Manchester.)

1878. Sopwith, Thomas, Mining Engineer, 6 Great George Street, Westminster, S.W.

1877. Soyres, Francis Johnstone de, Messrs. Bush and De Soyres, Bristol Iron Foundry, Bristol.

1876. Speck, Thomas Samuel, Resident Engineer and Locomotive Superintendent, Metropolitan District Railway, Lillie Bridge Works, West Brompton, London, S.W.

1878. Spencer, Alfred G., Messrs. George Spencer and Co., 77 Cannon Street, London, E.C.

1866. Spencer, Eli, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham; and The Hollies, Werneth, Oldham.

1878. Spencer, George, Messrs. George Spencer and Co., 77 Cannon Street, London, E.C.

1877. Spencer, John, Vulcan Tube Works, Westbromwich.

1867. Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne.

1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne.

1876. Spice, Robert Paulson, 21 Parliament Street, Westminster, S.W.

1864. Spittle, Thomas, Cambrian Iron Foundry, Newport, Monmouthshire.

1862. Stableford, William, Railway Carriage Works, Oldbury, near Birmingham.

1869. Stabler, James, 11 Elgin Gardens, Effra Road, Brixton, London, S.W.

1880. Stafford, George, Russell Street Lace-Curtain Works, Nottingham.

1877. Stanger, George Hurst, Queen's Chambers, North Street, Wolverhampton.

1875. Stanger, William Harry, 23 Queen Anne's Gate, Westminster, S.W.

1866. Stephens, John Classon, Messrs. Stephens and Co., Vulcan Iron Works, Sir John Rogerson's Quay, Dublin.

1874. Stephens, Michael, Locomotive Superintendent, Cape Government Railways, Cape Town, Cape of Good Hope.

1868. Stephenson, George Robert, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1879. Stephenson, Joseph Gurdon Leycester, 6 Drapers' Gardens, Throgmorton Street, London, E.C.

1876. Sterne, Louis, Messrs. Thomson Sterne and Co., Crown Iron Works, Glasgow; and 10 Victoria Chambers, Victoria Street, Westminster, S.W.

1875. Stevens, Arthur James, Uskside Iron Works, Newport, Monmouthshire.

1878. Stevenson, George Wilson, 4 Westminster Chambers, Victoria Street, Westminster, S.W.

1877. Stewart, Alexander, Manager, Messrs. Thwaites Brothers, Vulcan Iron Works, Thornton Road, Bradford.

1859. Stewart, Charles P., Messrs. Sharp Stewart and Co., Atlas Works, Manchester; and Silwood Park, Sunninghill, near Staines.

1878. Stewart, Duncan, Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow.

1851. Stewart, John, Blackwall Iron Works, Poplar, London, E.

1880. Stirling, James, Locomotive Superintendent, South Eastern Railway, Ashford.

1867. Stirling, Patrick, Locomotive Superintendent, Great Northern Railway, Doncaster.

1875. Stoker, Frederick William, Manager, Messrs. Johnson and Reay, The Moor Iron Works, Stockton-on-Tees.

1877. Stokes, Alfred Allen, Chief Assistant Locomotive Superintendent, East Indian Railway, Jumalpore, Bengal: (or care of Messrs. W. and H. M. Goulding, 108 Patrick Street, Cork.)

1864. Stokes, James Folliott, Longview, Simla, India: (or care of Charles P. B. Shelley, 45 Parliament Street, Westminster, S.W.)

1863. Storey, John Henry, Knott Mill Brass and Copper Works, Little Peter Street, Manchester.

1877. Stothert, George Kelson, Steam Ship Works, Bristol.

1865. Stroudley, William, Locomotive Superintendent, London Brighton and South Coast Railway, Brighton; and Bosvigo, Preston Park, Brighton.

1873. Strype, William George, The Murrough, Wicklow.

1861. Sumner, William, 2 Brazennose Street, Manchester.

1875. Sutcliffe, Frederic John Ramsbottom, Engineer, Low Moor Iron Works, near Bradford.

1880. Sutton, Thomas, Carriage and Wagon Superintendent, Furness Railway, Barrow-in-Furness.

1864. Swindell, James Swindell Evers, Queen's Chambers, 8 Cherry Street, Birmingham; and Clent House, Stourbridge.

1878. Taite, John Charles, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C.

1875. Tangye, George, Messrs. Tangye Brothers, Cornwall Works, Soho, Birmingham.

1861. Tangye, James, Messrs. Tangye Brothers, Cornwall Works, Soho, Birmingham; and Aviary Cottage, Illogan, near Redruth.

1879. Tartt, William, Superintending Engineer, Euphrates and Tigris Steam Navigation Company, Bussora and Bagdad: (or care of William Cole, 35 Grove Road, Regent's Park, London, N.W.)

1876. Taunton, Richard Hobbs, Messrs. Taunton and Hayward, Star Tube Works, Heneage Street, Birmingham.

1874. Taylor, Henry Enfield, Mining Engineer, 15 Newgate Street, Chester.

1858. Taylor, James, Britannia Engine Works, Cleveland Street, Birkenhead.

1862. Taylor, John, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.

1873. Taylor, John, Midland Foundry, Queen's Road, Nottingham.

1867. Taylor, Joseph, Corinthian Villa, Acock's Green, near Birmingham.

1875. Taylor, Joseph Samuel, Messrs. Taylor and Challen, Derwent Foundry, 99 Constitution Hill, Birmingham.

1874. Taylor, Percyvale, Panther Lead Smelting Works, Avon Street, St. Philip's, Bristol.

1862. Taylor, Richard, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.

1876. Taylor, William Henry Osborne, Panteg Steel and Engineering Works, Panteg, near Pontypool.

1864. Tennant, Charles, M.P., The Glen, Innerleithen, near Edinburgh. (*Life Member.*)

1877. Thom, William, Messrs. W. and J. Yates, Canal Foundry, Blackburn.

1867. Thomas, Joseph Lee, 16 Holland Road, Kensington, London, W.

1864. Thomas, Thomas, 19 The Parade, Cardiff.

1874. Thomas, William Henry, 15 Parliament Street, Westminster, S.W.

1875. Thompson, John, Highfields Boiler Works, Ettingshall, near Wolverhampton.

1857. Thompson, Robert, Victoria Chambers, Wigan; and Standish, near Wigan.

1880. Thompson, Thomas William, Messrs. Thompson and Gough, South Mersey Ferries, Birkenhead.

1862. Thompson, William, 116 Fenchurch Street, London, E.C.

1875. Thoms, George Eastlake, Borough Engineer, Town Hall, Wolverhampton.

1879. Thomson, David, 4 Cholmeley Park Villas, Highgate, London, N.

1875. Thomson, James McIntyre, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow.

1868. Thomson, John, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow.

1880. Thornbery, William Henry, Jun., Corporation Chambers, Ann Street, Birmingham.

1868. Thornewill, Robert, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.

1877. Thornton, Frederic William, Hydraulic Engineering Co., Palace Chambers, 9 Bridge Street, Westminster, S.W.

1876. Thornycroft, John Isaac, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W.

1875. Thwaites, William Henry, Messrs. Thwaites Brothers, Vulcan Iron Works, Thornton Road, Bradford.

1875. Tomkins, William Steele, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.

1857. Tomlinson, Joseph, Jun., Resident Engineer and Locomotive Superintendent, Metropolitan Railway, Chapel Street Works, Edgware Road, London, N.W.

1867. Tonks, Edmund, Brass Works, Moseley Street, Birmingham.

1876. Trevithick, Richard Francis, Locomotive Engineer, Central Argentine Railway, Rosario, Argentine Republic: (or care of M. Trevithick, The Cliff, Penzance.)

1873. Trow, Joseph, Messrs. William Trow and Sons, Union Foundry, Wednesbury; and Victoria House, Holyhead Road, Wednesbury.

1866. Turner, Frederick, Messrs. E. R. and F. Turner, St. Peter's Iron Works, Ipswich.

1876. Turney, John, Messrs. Turney Brothers, Trent Bridge Leather Works, Nottingham.

1872. Turton, Thomas, Liverpool Forge Company, Brunswick Dock, Liverpool.

1867. Tweddell, Ralph Hart, 14 Delahay Street, Westminster, S.W.

1856. Tyler, Sir Henry Whatley, K.C.B., M.P., Pymmes Park, Edmonton, Middlesex.

1877. Tylor, Joseph John, 11 Little Queen Street, Westminster, S.W.

1878. Tyson, Isaac Oliver, Ousegate Iron Works, Selby.

1875. Unsworth, Thomas, 79 Piccadilly, Manchester.

1878. Unwin, William Cawthorne, Professor of Engineering, Royal Indian Engineering College, Cooper's Hill, Staines.

1862. Upward, Alfred, 8 Queen Anne's Gate, Westminster, S.W.

1875. Urquhart, Thomas, Locomotive Superintendent, Grazi and Tsaritsin Railway, Borisoglebsk, Russia: (or care of John Maclachlan, 15 Hamilton Street, Greenock).

1880. Valon, William Andrew McIntosh, Engineer, Ramsgate Local Board, Hardres Street, Ramsgate.

1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.

1865. Vickers, Albert, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1861. Vickers, Thomas Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1856. Waddington, John, 35 King William Street, London Bridge, London, E.C.

1879. Wadia, Nowrosjee Nesserwanjee, Manager, Manockjee Petit Manufacturing Co., Tardeo, Bombay: (or care of Messrs. Hick Hargreaves and Co., Soho Iron Works, Bolton.)

1875. Wailes, John William, Patent Shaft Works, Wednesbury.

1881. Wake, Henry Hay, Engineer to the River Wear Commission, Sunderland.

1863. Wakefield, John, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Dublin.

1873. Waldenström, Eric Hugo, Manager, Broughton Copper Works, Broughton Road, Manchester.

1872. Walker, Alexander, 6 Llwyn Terrace, Oswestry.

1870. Walker, Alfred, Albion Iron Works, Aldwark, York.

1867. Walker, Benjamin, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds.

1867. Walker, Charles Clement, Midland Iron Works, Donnington, near Newport, Shropshire; and Lilleshall Old Hall, near Newport, Shropshire.

1877. Walker, David, Superintendent of Engineering Workshops, King's College, Strand, London, W.C.

1875. Walker, George, 95 Leadenhall Street, London, E.C.

1875. Walker, John Scarisbrick, Messrs. J. S. Walker and Brother, Pagefield Iron Works, Wigan; and 12 Ash Street, Southport.

1876. Walker, Thomas Ferdinand, Ship's Log Manufacturer, 58 Oxford Street, Birmingham.

1878. Walker, William, Kaliemaas, Alleyne Park, West Dulwich, London, S.E.

1863. Walker, William Hugill, Messrs. Walker Eaton and Co., Wicker Iron Works, Sheffield.

1878. Walker, Zaccheus, Jun., Fox Hollies Hall, near Birmingham.

1868. Wallis, Herbert, Mechanical Superintendent, Grand Trunk Railway, Montreal, Canada.

1865. Walpole, Thomas, Messrs. Ross and Walpole, North Wall Iron Works, Dublin.

1877. Walton, James, 28 Maryon Road, Charlton.

1881. Warburton, John Seaton, 60 Queen Victoria Street, London, E.C.

1876. Ward, William Meese, Limerick Foundry, Great Bridge, Tipton.

1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Handsworth, near Birmingham.

1856. Wardle, Charles Wetherell, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds.

1852. Warham, John R., Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.

1881. Warham, Richard Landor, Messrs. Thornewill and Warham, Severn Engineering Works, Derby.

1874. Warner, Edward, Messrs. Woods Cocksedge and Co., Suffolk Iron Works, Stowmarket.

1858. Waterhouse, Thomas, Claremont Place, Sheffield. (*Life Member.*)

1881. Watkins, Alfred, 62 South Street, Greenwich, S.E.

1862. Watkins, Richard, Messrs. Seaward and Co., Canal Iron Works, Millwall, London, E.

1866. Watson, Robert, Engineer, Brereton and Hayes Collieries, near Rugeley.

1879. Watson, William Renny, Messrs. Mirrlees Tait and Watson, Engineers, Glasgow.

1877. Watts, John, Broad Weir Engine Works, Bristol.

1877. Waugh, John, Chief Engineer, Yorkshire Boiler Insurance and Steam Users' Co., Sunbridge Chambers, Bradford.

1878. Weatherhead, Patrick Lambert, 3 Chaussée Strasse, Berlin.

1862. Webb, Francis William, Locomotive Superintendent, London and North Western Railway, Crewe.

1879. Weiss, Hubert August Otto, Messrs. Siemens Brothers, Telegraph Works, Charlton, Kent.

1872. Welch, Edward John Cowling, Palace Chambers, St. Stephen's, Westminster, S.W.

1862. Wells, Charles, Moxley Iron and Steel Works, near Bilston.

1876. West, Henry Hartley, Chief Surveyor, Underwriters' Registry for Iron Vessels, A13 Exchange Buildings, Liverpool.

1874. West, Nicholas James, Messrs. Harvey and Co., Hayle Foundry, Hayle.

1877. Western, Charles Robert, Messrs. Western and Co., Chaddesden Works, Derby; and Chaddesden Hill, Derby.

1877. Western, Maximilian Richard, care of Messrs. Western and Sons, 35 Essex Street, Strand, London, W.C.

1862. Westmacott, Percy Graham Buchanan, Sir William G. Armstrong and Co., Elswick Engine Works, Newcastle-on-Tyne; and Benwell Hill, Newcastle-on-Tyne.

1880. Westmoreland, John William Hudson, 228 Arkwright Street, Nottingham.

1867. Weston, Thomas Aldridge, care of J. C. Mewburn, 169 Fleet Street, London, E.C.; and 5 Bedford Terrace, Harpur Street, Bedford.

1880. Westwood, Joseph, Jun., Messrs. Westwood Baillie and Co., London Yard Iron Works, Poplar, London, E.; and 39 Great Tower Street, London, E.C.

1881. Wharton, William Augustus, Assistant Engineer, Nottingham Corporation Water Works, Maple Street, Nottingham.

1867. Wheatley, Thomas, Manager, Wigtownshire Railway, Wigtown Wigtownshire.

1856. Wheeldon, Frederick R., Highfields Engine Works, Bilston; and 45 Waterloo Road South, Wolverhampton.

1874. White, Henry Watkins, Chief Engineer, H.M. Dockyard, Simon's Town, Cape of Good Hope.

1864. White, Isaias, Messrs. Portilla and White, Engineers and Iron Ship Builders, Seville, Spain: (or care of Isaac White, Pontardulais, Llanelly.)

1876. Whiteley, William, Messrs. William Whiteley and Sons, Prospect Iron Works, Lockwood, Huddersfield.

1863. Whitley, Joseph, New British Iron Works, Corngreaves, near Birmingham.
1865. Whitley, Joseph, Railway Works, Hunslet Road, Leeds.
1869. Whittem, Thomas Sibley, Wyken Colliery, Coventry.
1847. Whitworth, Sir Joseph, Bart., D.C.L., LL.D., F.R.S., 44 Chorlton Street, Portland Street, Manchester; and Stancliffe, Matlock Bath; and 24 Great George Street, Westminster, S.W.
1878. Whytehead, Hugh Edward, 88 West Hill, Sydenham, London, S.E.
1859. Wickham, Lamplugh Wickham, Low Moor Iron Works, near Bradford.
1878. Wicks, Henry, Superintendent, Messrs. Burn and Co., Howrah Iron Works, Howrah, Bengal, India.
1878. Widmark, Harald Wilhelm, Helsingborgs Mekaniska Verkstad, Helsingborg, Sweden.
1868. Wigram, Reginald, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.
1881. Wigzell, Eustace Ernest, 37 Walbrook, London, E.C.
1877. Wilkinson, Robert, Fryer Concrete Co., Antigua, West Indies.
1874. Williams, David, Manager, Pontypool Iron and Tinplate Works, Pontypool.
1865. Williams, Edward, Cleveland Lodge, Middlesbrough.
1847. Williams, Richard, Patent Shaft Works, Wednesbury.
1859. Williams, Richard Price, 38 Parliament Street, Westminster, S.W.
1881. Williams, William Freke Maxwell, Trading Steamship Co., 137 Fenchurch Street, London, E.C.
1873. Williams, William Lawrence, 2 Westminster Chambers, Victoria Street, Westminster, S.W.
1870. Willman, Charles, Exchange Place, Middlesbrough.
1878. Wilson, Alexander, Messrs. Wilson Cammell and Co., Steel Works, Dronfield, near Sheffield.
1872. Wilson, Alfred, Messrs. Tangye's Steel Works, Soho, near Birmingham.
1859. Wilson, George, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.
1867. Wilson, Henry, Phœnix Brass Works, Stockton-on-Tees.
1881. Wilson, John, 9 Dean's Yard, Westminster, S.W.
1863. Wilson, John Charles, 5 Westminster Chambers, Victoria Street, Westminster, S.W.
1879. Wilson, Joseph William, Principal of School of Practical Engineering, Crystal Palace, Sydenham, S.E.
1857. Wilson, Robert, F.R.S.E., Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester.
1880. Wilson, Robert, 24 Poultry, London, E.C.
1873. Wilson, Thomas Sipling, care of Messrs. James Bischoff and Sons, 10 St. Helen's Place, London, E.C.

1881. Wilson, Wesley William, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin.

1867. Winby, Frederick Charles, St. Stephen's Palace Chambers, 9 Bridge Street, Westminster, S.W.

1872. Winstanley, Robert, Mining Engineer, 32 St. Ann's Street, Manchester.

1859. Winter, Thomas Bradbury, 53 Moorgate Street, London, E.C.

1872. Wise, William Lloyd, 7 Whitehall Place, London, S.W.

1871. Withy, Edward, Messrs. Withy and Co., Middleton Ship Yard, West Hartlepool.

1878. Wolfe, John Edward, care of G. W. Wucherer, H.B.M. Vice-Consul, Jaragua, Maceio, Brazil: (or care of Richard R. Wolfe, Arthington, Torquay.)

1878. Wolfenden, Richard, Chief Engineer, Chinese Cruiser "Yang Tse"; care of Chinese Customs Agency, Hong Kong, China.

1878. Wolfenden, Robert, Engineer and Millwright, Shanghai, China: (or care of Frederick Degenaer, Zetland Street, Hong Kong, China.)

1881. Wood, Edward Malcolm, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1868. Wood, Lindsay, Mining Engineer, Southhill, near Chester-le-Street.

1876. Wood, Thomas, Mining Engineer, North Hetton Collieries, Fence Houses.

1873. Woodhead, John Proctor, 54 John Dalton Street, Manchester.

1874. Worsdell, Thomas William, London and North Western Railway, Locomotive Department, Crewe.

1877. Worssam, Henry John, Messrs. G. J. Worssam and Son, Wenlock Road, City Road, London, N.

1876. Worssam, Samuel William, Oakley Works, King's Road, Chelsea, London, S.W.; and 38 Carlyle Square, King's Road, Chelsea, London, S.W.

1860. Worthington, Samuel Barton, Resident Engineer, London and North Western Railway, Victoria Station, Manchester; and 12 York Place, Oxford Road, Manchester.

1866. Wren, Henry, Messrs. Wren and Hopkinson, London Road Iron Works, Manchester.

1881. Wrench, John Mervyn, Resident Engineer, Scinde Punjaub and Delhi Railway, Lahore, India.

1881. Wright, Benjamin Frederick, Locomotive and Carriage Superintendent, Japanese Government Railways, Kobe, Japan: (or care of Messrs. Malcolm Brunker and Co., 22 St. Mary Axe, London, E.C.)

1870. Wright, George Benjamin, Goscote Iron Works, near Walsall.

1878. Wright, George Howard, Mining Engineer, 12 Trumpington Street, Cambridge.

1876. Wright, James, Messrs. Ashmore and White, Hope Iron Works, Bowesfield, Stockton-on-Tees.

1867. Wright, John Roper, Messrs. Wright Butler and Co., Elba Steel Works, Gower Road, near Swansea.

1859. Wright, Joseph, Metropolitan Railway Carriage and Wagon Co., Saltley Works, Birmingham; and 85 Gracechurch Street, London, E.C.

1860. Wright, Joseph, Neptune Forge, Chain and Anchor Works, Tipton; and Verona House, 2 Sterling Road, Edgbaston, Birmingham.

1863. Wright, Owen, Broadwell Forge, Oldbury, near Birmingham.

1878. Wright, William Barton, Locomotive Superintendent, Lancashire and Yorkshire Railway, Victoria Station, Manchester.

1871. Wrightson, Thomas, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.

1865. Wyllie, Andrew, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool.

1877. Wyvill, Frederic Christopher, Schloss Holte, Westphalen, Germany.

1878. Yates, Henry, Brantford, Ontario, Canada.

1881. Yates, Louis Edmund Hasselts, Assistant Locomotive Superintendent, Punjaub Northern State Railway, Jhelum, Punjaub, India: (or care of Rev. H. W. Yates, 98 Lansdowne Place, Brighton.)

1880. Yates, William, Locomotive Works, Lancashire and Yorkshire Railway, Miles Platting, Manchester.

1879. Yeomans, David Maitland, 63 Queen Victoria Street, London, E.C.; and 13 Lexham Gardens, Cromwell Road, London, W.

1879. Young, George Scholey, Messrs. T. A. Young and Son, Orchard Place, Blackwall, London, E.

1874. Young, James, Managing Engineer, Lambton Colliery Works, Fence Houses.

1879. Young, James, Low Moor Iron Works, near Bradford.

1881. Younger, Robert, Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.

1861. Yule, William, Messrs. J. H. Young and Co., 53 Mill Street, Bridgeton, Glasgow.

1880. Ziffer, Ferdinand Henry, Messrs. Ziffer and Walker, 6 Exchange Street, Manchester.

ASSOCIATES.

1880. Allen, William Edgar, Well Meadow Steel Works, Sheffield.
1880. Bagshawe, Washington, Messrs. John Spencer and Sons, Newburn Steel Works, Newcastle-on-Tyne.
1881. Barcroft, Henry, Bessbrook Spinning Works, County Armagh, Ireland.
1867. Blinkhorn, William, London and Manchester Plate Glass Works, Sutton, St. Helen's.
1879. Clowes, Edward Arnott, Messrs. William Clowes and Sons, Duke Street, Stamford Street, London, S.E.
1866. Crossley, John, British Plate Glass Works, Ravenhead, near St. Helen's.
1867. Dewhurst, John Bonny, Bellevue Cotton Mills, Skipton.
1863. Forster, George Emmerson, Contractor's Office, Washington, County Durham.
1865. Gössell, Otto, 41 Moorgate Street, London, E.C.
1878. Grosvenor, The Right Hon. Lord Richard De Aquila, M.P., 12 Upper Brook Street, Grosvenor Square, London, W.
1880. Haggie, David Henry, Wearmouth Rope Works, Sunderland.
1874. Hardcastle, Robert Anthony, Monk Bridge Iron Works, Leeds.
1859. Leather, John Towlerton, Leventhorpe Hall, near Leeds. (*Life Associate.*)
1865. Longsdon, Alfred, 2 Crown Buildings, Queen Victoria Street, London, E.C.
1881. Lowood, John Grayson, Gannister Works, Attercliffe Road, Sheffield.
1860. Manby, Cordy, Messrs. Moore and Manby, Castle Street, Dudley.
1868. Matthews, Thomas Bright, Messrs. Turton Brothers and Matthews, Phœnix Steel Works, Sheffield.
1874. Paget, Berkeley, Low Moor Iron Office, 2 Laurence Pountney Hill, Cannon Street, London, E.C.
1865. Parry, David, Leeds Iron Works, Leeds.
1874. Pepper, Joseph Ellershaw, Clarence Iron Works, Leeds.
1877. Render, Frederick, Crown Corn Mills, Stanley Street, Salford, Manchester,
1878. Roeckner, Carl Heinrich, 4 Royal Arcade, Newcastle-on-Tyne.
1875. Schofield, Christopher J., Vitriol and Alkali Works, Clayton, near Manchester.
1878. Stuart, James, Professor of Mechanism in Cambridge University, Trinity College, Cambridge.
1869. Varley, John, Farnley Iron Works, Leeds.
1875. Waslekar, Nanaji Narayan, care of Anglo-Vernacular Press, New Nagpada, Tank Street, Bycalla, Bombay, India.
1878. Watson, Joseph, Attorney General's Chambers, New Court, Temple, London, E.C.

GRADUATES.

1881. Alexander, Edward Disney, Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.

1874. Allen, Frank, Messrs. Allen Alderson and Co., Gracechurch Street, Alexandria: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1880. Anderson, Edward William, Messrs. Easton and Anderson, Erith Iron Works, Erith, London, S.E.

1878. Appleby, Charles, Jun., Messrs. Appleby Brothers, East Greenwich Works, London, S.E.

1878. Armstrong, Joseph, Great Western Railway Works, Swindon.

1872. Armstrong, Thomas, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1879. Arteaga, Alberto de, care of Juan J. de Arteaga, Rincon 62, Monte Video, Uruguay: (or care of Messrs. Hartog Reeves and Co., 13 Cullum Street, London, E.C.)

1879. Bagot, Alan Charles, Messrs. Apps and Bagot, 433 Strand, London, W.C.

1869. Bainbridge, Emerson, Nunnery Colliery Offices, New Haymarket, Sheffield.

1881. Beesley, David Stanley, Messrs. Stanford and Beesley, 89 Dartmouth Street, Birmingham.

1880. Benham, Percy, Messrs. Benham, 50 Wigmore Street, London, W.

1880. Birkett, Herbert, Messrs. J. and E. Hall, Iron Works, Dartford.

1880. Bright, Thomas Smith, Picton Villa, Carmarthen.

1878. Brooke, Arthur, Messrs. A. Paget and Co., Loughborough.

1880. Buckle, William Harry Ray, Bootham, York.

1878. Buddicom, Harry William, Penbedw Hall, Mold, Flintshire.

1879. Burnet, Lindsay, Messrs. John Norman and Co., Keppoch Hill Engine Works, 475 New Keppoch Hill Road, Glasgow.

1881. Clench, Gordon McDakin, Messrs. Robey and Co., Perseverance Iron Works, Lincoln.

1881. Compton-Bracebridge, John Edward, Messrs. Easton and Anderson. 3 Whitehall Place, London, S.W.

1879. Dady, Jamsetjee Nesserwanjee, 4 Cawasjee Patell Street, Fort, Bombay, India.

1876. Davis, Joseph, Lancashire and Yorkshire Railway, Engineer's Office, Manchester.

1875. Dawson, Edward, The Cottage, Chilton Moor, Fence Houses.

1873. Dobson, Richard Joseph Caistor, Gemör Fabrik, Kendal, Samarang, Java: (or care of Charles E. S. Dobson, 4 Chesterfield Buildings, Victoria Park, Clifton, Bristol.)

1868. Dugard, William Henry, Messrs. Dugard Brothers, Vulcan Rolling Mills, Bridge Street West, Summer Lane, Birmingham.

1873. Edmunds, John Sharp Wilbraham, Sheepcote Street Works, Sheepcote Street, Birmingham.

1875. Ffolkes, Martin William Brown, 28 Davies Street, Grosvenor Square, London, W.

1880. Francis, Archibald Adley, Locomotive Works, Great Eastern Railway, Stratford, London, E.

1879. Frossard, Charles Edouard, care of Hubert Waddy, Canal Company's Office, Gloucester.

1878. Greig, Alfred, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1877. Heaton, Arthur, Messrs. Heaton and Dugard, Metal and Wire Works, Shadwell Street, Birmingham.

1874. Hedley, Henry, Coppa Colliery, near Mold, Flintshire.

1874. Hedley, Thomas, 13 Elm Vale, Fairfield, Liverpool.

1879. Hesketh, Everard, Messrs. J. and E. Hall, Iron Works, Dartford.

1867. Holland, George, Mechanical Department, Grand Trunk Railway, Montreal, Canada.

1879. Howard, J. Harold, Britannia Iron Works, Bedford.

1877. Jeffreys, Edward Homer, Monk Bridge Iron Works, Leeds; and Gipton Lodge, Leeds.

1880. Jenkins, Rhys, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds; and 1 Bagley Square, Leeds.

1881. Lawson, James Ibbs, New Zealand Railways, Dunedin, Otago, New Zealand.

1881. Lockyer, Norman Joseph, Manchester Sheffield and Lincolnshire Railway, Gorton, Manchester.

1879. Lowthian, George, 8 Delahay Street, Westminster, S.W.

1881. Macdonald, Ranald Mackintosh, New Zealand Railways, Christchurch, New Zealand.

1878. Mannock, Thomas, Messrs. Higginbottom and Mannock, Crown Iron Works, Hyde Road, West Gorton, Manchester.

1868. Mappin, Frank, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.

1881. Milles, Robert Sydney, Borough Engineer's Office, Town Hall, Wolverhampton.

1867. Mitchell, John, Swaithe Colliery, Barnsley.

1868. Moor, William, Jun., Hetton Colliery, Hetton, near Fence Houses.

1872. Napier, Robert Twentyman, Yoker, Dumbartonshire.

1878. Newall, John Walker, Forest Hall, Ongar, Essex.

1881. Norris, Moraston Ormerod, Assistant Engineer, Public Works Department, India; 47 Cheltenham Street, New Swindon, Swindon.

1881. Oswell, William St. John, 20 Budge Row, London, E.C.

1876. Owen, George Charles Mickleburgh, Mechanical Engineer's Office, London and North Western Railway, Crewe.

1880. Parsons, The Hon. Charles Algernon, 10 Connaught Place, London, W.

1880. Paterson, Walter Saunders, London Brighton and South Coast Railway, Locomotive Department, London Bridge, London, S.E.

1870. Pearson, Thomas Henry, Moss Side Iron Works, Ince, near Wigan.

1879. Phillips, Robert Edward, 37 Great George Street, Westminster, S.W.

1881. Rogers, Philip Powys, Assistant Engineer, Warda Coal State Railway, Warora, Central Provinces, India.

1881. Scott, Ernest, Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.

1875. Sheppard, Herbert Gurney, Imperial Brazilian Natal and Nova Cruz Railway, Natal, Pernambuco, Brazil: (or care of C. L. Sheppard, The Hall, Welwyn.)

1879. Solly, Arthur John, Heathfield, Congleton.

1877. Spielmann, Marion Harry, 16 Porchester Terrace, Hyde Park, London, W.

1874. Taylor, Arthur, Pontgibaud Lead Works, Puy de Dôme, France; and 6 Queen Street Place, Upper Thames Street, London, E.C.

1878. Waddington, John, Jun., 35 King William Street, London Bridge, London E.C.

1875. Walker, Arthur Henry, Guild Hall Chambers, Cardiff.

1881. Walkinshaw, Frank, 17 Eaton Square, London, S.W.

1880. Weymouth, Francis Marten, Mill Hill, London, N.W.

1877. Whitelock, William Thomas Grant, Bowling Iron Works, near Bradford.

1868. Wicksteed, Joseph Hartley, Well House Foundry, Meadow Road, Leeds.

1879. Wood, Edward Walter Naylor, Annandale House, Bangor.

1880. Wood, John Mackworth, Engineer's Department, New River Water Works, Clerkenwell, London, E.C.; and 51 College Street, Islington, London, N.

1880. York, Francis Colin, 28 Calverley Street, Tunbridge Wells.

Institution of Mechanical Engineers.

MEMOIRS

OF MEMBERS DECEASED IN 1880.

SIR THOMAS BOUCH was born on 25th February 1822, at Thursby, near Carlisle, his father being a captain in the merchant service. On leaving school he was apprenticed to Mr. G. Larmer, civil engineer; and after superintending railway works in different parts of England was appointed resident engineer for the Wear Valley line. In 1849 he became manager and engineer of the Edinburgh and Northern Railway, to Perth and Dundee, now a part of the North British system. Here he designed and carried out the method still in operation of transporting railway goods wagons across the Forth and Tay ferries, by running them upon rails laid on the decks of ferry steamers. In 1851 he commenced business on his own account as a civil engineer in Edinburgh, and was engaged as engineer for numerous railways in Scotland, as well as for several in England. Among the former may be mentioned the Peebles Railway, the Edinburgh and Roslin, the Glasgow and Coatbridge, and the Arbroath and Montrose; and among the latter, the Darlington and Barnard Castle Railway, the Eden Valley Railway, the Cockermouth and Penrith, and the Maidstone and Sevenoaks. His labours included the designing of several extensive bridges, including the Deepdale and Beelah viaducts, the Redheugh bridge at Newcastle, and the Tay bridge, on the completion of which last he received the honour of knighthood. Its subsequent deplorable fall during the hurricane of 28th December 1879 is believed to have hastened his death, which took place at Moffat on 30th October 1880, in the fifty-ninth year of his age. He became a Member of the Institution in 1862.

Thomas Broadbent was born at Kirkheaton, near Huddersfield, on 5th October 1833. After being educated at Huddersfield College, and serving an apprenticeship to Mr. Richard Armitage in that town, he commenced business at Milnsbridge near Huddersfield as mechanical engineer and millwright, in partnership with Mr. B. J. Shaw, a fellow apprentice. On the dissolution of the partnership in 1868 he commenced business for himself at Huddersfield. He was the architect and engineer of the Slaithwaite Spinning Mill, the largest concern in the district; and erected the winding gear for hauling up clay wagons on the inclined plane at Wessenden Head, for the construction of the Huddersfield waterworks reservoir. He was frequently consulted in other engineering works of the town. Shortly before his death he introduced an improvement in hydro-extractors, for sugar refining, drying purposes, &c., employing a small steam engine to drive the machine direct at a speed of 1200 revs. per min. His death took place on 5th December 1880, at the age of forty-seven, from typhoid fever. He became a Member of the Institution in 1875.

Thomas Checkley was born at Ettingshall, near Wolverhampton, on 7th June 1834, his father, Mr. William Checkley, being a mining engineer. After being educated at Queen Mary's School, Walsall, he followed the same profession in that town, where he also took a prominent part in all public affairs, being twice elected mayor, and subsequently appointed one of the borough justices. He was interested in several collieries in the neighbourhood, in the management of which he took a very active part. In 1875, in reporting upon proposals made for sinking for the Thick Coal under the New Red Sandstone, on the Hamstead estate near Birmingham, he predicted that it would be found at a depth of about 600 yards; and in 1880 it was so found at 615 yards, of a thickness between 20 and 30 feet; and this in a neighbourhood where no previous attempt had been made for its discovery. At the inundation of the Pelsall Colliery he rendered great assistance in the efforts to extricate the men and to relieve the sufferers, and subsequently prepared a very able report on the disaster. After a very painful illness he

died at Walsall on 23rd September 1880, at the age of forty-six. He became a Member of the Institution in 1869.

William Clark was born at Colchester on 17th March 1821; and after being educated principally at King's College, London, entered the office of Mr. J. Birkinshaw, under whom he was employed for three or four years on the York and North Midland Railway works. In 1850 he became connected with Sir Goldsworthy Gurney, at that time occupied with the warming and ventilation of the Houses of Parliament; and in 1851 he joined Mr. A. W. Makinson in works of that class. Shortly afterwards he was appointed surveyor to Kingston-upon-Hull, for which town he planned a complete system of drainage, and commenced the necessary works. In 1854 he became resident engineer on a portion of the East Indian Railway; and a year later secretary, and afterwards engineer, to the municipality of Calcutta, for whom he devised a thorough drainage scheme, which he ultimately carried out with complete success and with great benefit to the public health. He also planned and carried out a complete system of waterworks for Calcutta; and continued to act as engineer-in-chief to that municipality until 1874, when he returned to England and entered into partnership with Mr. W. F. Batho. At the end of the same year he visited Madras, and there planned a drainage scheme for that city. He was also appointed consulting engineer to the Oude and Rohilkund Railway. In 1876 he was commissioned by the New South Wales Government to report and advise upon the water supply and drainage of Sydney; and while in Australia he also prepared similar schemes for Port Adelaide, Newcastle, Bathurst, Goulburn, Orange, Maitland, and Brisbane, as well as afterwards for Wellington and Christchurch in New Zealand. The works of his drainage scheme for Christchurch were commenced in 1879, the sewage pumping machinery being designed and sent out under his supervision. He invented a "tied brick arch," of which fine examples were constructed in Calcutta and elsewhere in India; and was associated with Mr. Batho in the introduction of a steam road roller. After suffering for about half a year from a liver affection, he died at Surbiton on 22nd January 1880, at the age of fifty-eight. He became a Member of the Institution in 1867.

Thomas Elwell was born in London on 20th May 1812. After serving his time as apprentice millwright in the works of Messrs. Rennie, London, he was engaged in 1837 as foreman in the engineering works of Messrs. Sanford and Varrall, Paris, who were at that time beginning business, and introducing into France the machinery suitable for the manufacture of paper. Mr. Elwell took part in erecting in France the first paper mills worked by machinery; he was afterwards engaged in designing general engineering machinery, such as pumping engines, steam engines, and machine tools. He became subsequently manager, and ultimately partner, in the firm of Messrs. Varrall Elwell and Middleton, which under his management has been held in high repute by the French Admiralty and War offices, the railways, and mechanical establishments. They obtained a "Grand Prix" at the Paris Exhibition in 1878, when for his long and valued services in France Mr. Elwell received the Cross of "Chevalier de la Légion d'Honneur." He was a Member of the Société des Ingénieurs Civils, Paris. He died suddenly in Toulon on 3rd April 1880, in the sixty-eighth year of his age, from an attack of apoplexy. He became a Member of the Institution in 1860.

Thomas Hawthorn, eldest son of the late Dr. Hawthorn of Newcastle-on-Tyne, was born on 19th April 1838, and lost his life on 18th August 1880, by a fall from the Stüsberg, between Seilisberg and Beckenried, Lake of Lucerne. He was educated at Dr. Bruce's academy, and served his apprenticeship as a mechanical engineer with Messrs. Robert Stephenson & Co., Newcastle on-Tyne. In 1861 he obtained the responsible position of assistant engineer at the docks and warehouses at Marseilles, which he held until 1865. He then returned to the Tyne, and in conjunction with Mr. William Black established locomotive, marine, and stationary engine works at Gateshead, under the firm of Messrs. Black Hawthorn & Co. In 1867 they introduced an axle for locomotives having six or more coupled wheels, whereby lateral play is given to the trailing wheels, easing the motion round sharp curves, and diminishing the wear and tear of both engines and permanent way. This was favourably criticised at the time of its introduction, and has since been applied

to a great number of main-line and shunting engines. At the time of his decease Mr. Hawthorn was engaged upon a street tramway locomotive, which is now being perfected. He became a Member of the Institution in 1880.

WILLIAM EBENEZER MARSHALL was born in 1824 at Kendal, where his father, Mr. Samuel Marshall, conducted a school as successor to the celebrated Dr. John Dalton. After serving an apprenticeship to Messrs. Kitson Thompson and Hewitson, Leeds, in 1852 he joined Mr. W. E. Carrett and Mr. John Telford in the Sun Foundry, Leeds, under the firm of Carrett Marshall and Co. Among other machines brought out by the firm were Carrett's steam-pump and Joy's hydraulic organ-blower. In 1859 he acted as honorary local secretary on the occasion of the first meeting of the Institution held in Leeds. In 1872 he retired from the Sun Foundry; and afterwards resided for some years in Scarborough. His death occurred in Leeds on 8th June 1880, at the age of fifty-six, after a brief illness. He became a Member of the Institution in 1859.

General ARTHUR JULES MORIN was born in Paris on 17th October 1795, and received his early education in Italy, but returned to Paris before 1814 and completed his mathematical studies at the Ecole Polytechnique; after which he entered the artillery service, and in 1823 took part as lieutenant in the Spanish war. He was then appointed assistant professor of mechanics in the Artillery and Military Engineering School at Metz. Here he edited the first publications of Poncelet, whom he shortly afterwards succeeded there as professor. His celebrated experiments on friction, slipping, rolling, traction, and belts, were carried out at Metz, the success of his researches being largely due to the use of different forms of dynamometer devised by himself. In 1839 a professorship of Applied Mechanics was specially established for him at the Conservatoire des Arts et Métiers, Paris, of which in 1849 he was appointed the Director. In 1844 he was elected into the Academy of Sciences of the Institute of France. He was a juror in the London Exhibitions of 1851 and 1862, and a general commissioner for the Paris

Exhibition of 1855. His "Aide Mémoire" is one of the most popular of the French works known in England; and his treatises on practical mechanics, steam engines, pumps, hydraulic motors, strength of materials, and ventilation and warming, rank as standard works. He carried out the ventilation of the Corps Législatif, and of the Opera, Châtelet, Gaieté, Lyrique, and Vaudeville theatres in Paris; and was concerned also in the sanitary arrangements of various large hospitals. For many years he was a director of the Northern Railway of France. In 1867, on the occasion of the first meeting of the Institution held in Paris, he was nominated by the Council an Honorary Life Member of the Institution, in recognition of the valuable aid received from him as Director of the Conservatoire des Arts et Métiers; and at that meeting he contributed a paper on the Ventilation of public buildings, describing his system of ventilation as carried out in the Conservatoire, the Théâtre Lyrique, and one of the public schools. The Institution enjoyed the advantage of a renewal of the same good offices, on the part both of himself and of the establishment which he directed, when the Paris meeting was repeated in 1878. His death took place on 7th February 1880, after a short illness, in the middle of his eighty-fifth year.

Lewis Olrick was born at Frederiksborg in Denmark, on 26th September 1827, and after leaving college served his time in a marine engineering shop, and then entered the Danish navy as an engineer. About 1849 he came to London, and was employed with Messrs. Maudslay Sons & Field; and afterwards became manager to an engineering firm in the North of England. About 1858 he started in business for himself as a consulting engineer in London, and was engaged as scientific witness in numerous patent cases. For many years past he manufactured and successfully introduced the "Field" boilers and tubes. His death took place from an apoplectic seizure on 21st August 1880, in the fifty-third year of his age. He became a Member of the Institution in 1867.

Millin Selby was born at Courtown, near Gorey, county Wexford, Ireland, on 26th January 1830; and was educated at

Brucke Hall School, Warrington. After serving the usual period of pupilage as a mechanical engineer, he was engaged by Messrs. de Jersey of Manchester in 1856 to proceed to Russia to erect the machinery for a large cotton mill near Moscow. On completion of this he was employed by Messrs. Karetnikoff of Teakova to superintend the erection there of cotton spinning mills and weaving sheds, dye and bleach works, &c., of which he afterwards conducted the management successfully for upwards of nineteen years. In 1876 he returned to England, and soon afterwards bought the works of the Patricroft Spinning Co.; these he carried on until his death, which took place on 12th July 1880, after a short illness. He became a Member of the Institution in 1867.

Institution of Mechanical Engineers.

PROCEEDINGS.

JANUARY 1881.

The THIRTY-FOURTH ANNUAL GENERAL MEETING of the Institution was held at the Institution of Civil Engineers, London, on Thursday, 27th January, 1881, at Half-past Seven o'clock p.m.; EDWARD A. COWPER, Esq., President, in the chair.

The Minutes of the last Meeting were read, approved, and signed by the President.

The PRESIDENT announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and the following New Members, Associate, and Graduates were found to be duly elected :—

MEMBERS.

JOHN AUDLEY FREDERICK ASPINALL,	Dublin.
JOHN DAVIS BARNETT,	Stratford, Canada.
THOMAS BRADLEY,	Newark.
CHARLES JOHN COPELAND,	Barrow-in-Furness.
HEBER DUCKHAM,	London.
THOMAS BUTTWELL EWEN,	Birmingham.
ALFRED SEALE HASLAM,	Derby.
THOMAS JEFFERISS,	Birmingham.
CECIL BROOKE PALMER,	Nottingham.
ANTHONY PATTERSON,	Ulverston.
JOHN PATTINSON,	Kosloff, Russia.
CHARLES HOLLOWAY REED,	Sunderland.
CHARLES SANDIFORD,	Lahore, India.
WILLIAM WEALLENS SHANKS,	London.

WILLIAM SISSON, ...	Falmouth.
JOHN SEATON WARBURTON, . .	London.
WILLIAM FREKE MAXWELL WILLIAMS, .	London.
WESLEY WILLIAM WILSON, . .	Dublin.

ASSOCIATE.

HENRY BARCROFT, ...	Armagh.

GRADUATES.

JOHN EDWARD COMPTON-BRACEBRIDGE,	London.
JAMES IBBS LAWSON, . . .	Christchurch, New Zealand.
RANALD MACKINTOSH MACDONALD, .	Christchurch, New Zealand.

The following Annual Report of the Council was then read:—

ANNUAL REPORT OF COUNCIL.

1881.

The Council have pleasure in laying the following Annual Report before the Meeting, on this occasion of the Thirty-fourth Anniversary of the Institution.

At the end of the year 1880 the total number of names of Members of all classes on the roll of the Institution was 1210, as compared with 1178 at the corresponding period of the previous year. The increase arises as follows:—there were elected within the year 80 Members of all classes; there were lost from the register by deceases 8 names of all classes, and by resignation or removal 40 names of all classes. This effective increase of 32 is highly satisfactory, considering the position in which engineers in general have been placed during the past year, being fully equal to the average annual increase in the Institution.

The following Deceases of Members of the Institution have occurred during the past year:—

Sir Thomas Bouch,	Edinburgh.
Thomas Broadbent,	Huddersfield.
Thomas Checkley,	Walsall.
William Clark,	London.
Thomas Elwell, Sen.,	Paris.
Thomas Hawthorn,	Gateshead.
William Ebenezer Marshall,	Leeds.
General Arthur Morin,	Paris.
Lewis Olrick,	London.
Millin Selby,	Patricroft.

Of these General Morin, Director of the Conservatoire des Arts et Métiers, was an Honorary Life Member of the Institution, having been so nominated by the Council on the occasion of the first meeting of the Institution in Paris in 1867.

The following gentlemen have resigned their Membership in the Institution during the past year:—

William George Beattie,	London.
John Addison Birkbeck,	Middlesbrough.
James Irving Carson,	Annan.
Walter Chamberlain,	Birmingham.
Charles Clayton,	Preston.
Robert Moss Collingham,	Hull.
William Hackney,	Newport, Mon.
William Edward Heap,	Rochdale.
Wilson Lloyd,	Wednesbury.
William Moor,	Hetton.
John Edward Pearson (Graduate),	Newton-le-Willows.
Thomas Dyne Steel,	Newport, Mon.
James Evers Swindell,	Stourbridge.
Enrique de Vial (Associate),	Santander.

The following gentlemen have ceased to be Members of the Institution during the past year:—

Henry Berriman Cuss,	Manchester.
John Gillett,	Melksham.
John R. Griffiths,	Pontypool.

ROBERT GRUNDY, ...	Wigan.
JOSEPH HOLIDAY, ...	Bradford.
HENRY KINSEY, ...	Swansea.
JAMES LEES, ...	Derby.
ALEXANDER MCNEILE, ...	London.
WILLIAM PRIDEAUX NAISH, ...	Birmingham.
WILLIAM MANFIELD NEWTON, ...	London.
JOHN JAMES TROW, ...	Wednesbury.
JOHN WILLIAM WASS, ...	Newcastle-on-Tyne.
JOHN WITHINSHAW, ...	Birmingham.

The accounts for the year 1880, having been passed by the Finance Committee, and having been audited by Messrs. Robert A. McLean & Co., Public Accountants, are now submitted to the Members (*see Appendix I.*). It will be seen that the receipts for the year have been £4085 11*s.* 7*d.*, while the expenditure has been £3325 7*s.* 10*d.*, showing a balance of receipts over expenditure of £760 3*s.* 9*d.* A Balance Sheet is also appended, showing the financial position of the Institution at the end of the year to be thoroughly satisfactory. It will be seen that the total investments and other assets amounted to £13,164 9*s.* 5*d.*, and that the liabilities were *nil*, the capital of the Institution at the end of the year being therefore £13,164 9*s.* 5*d.* The greater part of this, as will be seen, is invested in Four per cent. Railway Debenture Stocks, registered in the name of the Institution.

Referring to the subject of Experimental Research, the Committee on the Hardening, Tempering, and Annealing of Steel were enabled to avail themselves of a very generous offer made by Professor Williamson, F.R.S., to carry out a series of analyses of hardened and unhardened steel, at the Laboratory, University College, London. Much time has been expended upon these experiments, owing to the great difficulty of finding any system of analysis that would give conclusive data on the particular points on which the Committee wished for information; but the Committee expect now to have the final results in their hands at an early date. Upon Riveted Joints a long and valuable series of experiments has generously been carried out at University College by Professor Kennedy, with his excellent

testing machine; the steel being supplied by the Landore Steel Co., and the specimens prepared by the Wallsend Slipway Co., in the most liberal manner, and in both cases free of expense to the Institution. The Council feel that the thanks of the Institution are due to all these gentlemen for their kind assistance, in thus enabling the Committee to conduct an investigation which they believe will be found of great practical value. The results would have been already in the hands of the Members, but that it was considered desirable to check them by some final experiments on a larger scale, but embodying in fact the results of the investigations already made. These experiments are now in progress, the Barrow Hæmatite Steel Co. having kindly offered the use of their large testing machine for the purpose; and it is hoped that the results of the enquiry will shortly be in a condition to be laid before the Institution.

The Library of the Institution has been considerably augmented during the past year, by the books purchased with the bequest of £100, received in February from the executors of the late Mr. Robert Napier, Past-President. Of these a list is appended, and it will be seen that they consist mainly of standard works of reference, in connection with the several branches of mechanical science. They are arranged as a separate portion of the library, and lettered as the Napier Bequest. The library has further received donations of £10 10*s.* from Mr. R. A. McLean, auditor to the Institution, £10 10*s.* from the President, and £1 1*s.* from Mr. M. M. Brophy; and many valuable contributions of books &c., as will be seen by the list appended. The Council trust that the example thus set by some of the Members and friends of the Institution will be largely followed by others, in the donation of books, pamphlets, drawings, or original reports; and in particular of all publications giving the results of experiments or researches made by Members of the Institution or their friends.

In view of the large increase of the Library, a new Catalogue has been prepared, which will shortly be in the hands of the Members.

(*For List of Donations see Appendix II.*)

The Meetings held in 1880 were the Annual General Meeting and the Spring Meeting, both in London, and lasting two days each, the Summer Meeting of three days at Barrow-in-Furness, and the Autumn Meeting in Manchester. Thus eight days in all were devoted to the reading and discussion of Papers, the list of which, as published in the Proceedings, is as follows:—

Reply on the Discussion upon Fireless Locomotives; by M. Léon Francq.

On Brown's Tramway Locomotive; by Mr. B. C. Browne.

On Improvements in Machinery for Rolling Iron and Steel Plates; by Mr. Edward Hutchinson.

Is Automatic Action necessary or desirable in a Continuous Railway Brake? by Mr. T. Hurry Riches.

On the Structure of Cast-Steel Ingots, by D. Chernoff; translated by Mr. William Anderson.

On Permanent Way for Street Tramways, with special reference to Steam Traction; by Mr. J. D. Larsen.

Remarks on Chernoff's Papers on Steel; by Mr. William Anderson.

On Water-Pressure Engines for Mining purposes; by Mr. Henry Davey.

On Electric Lighting; by Dr. John Hopkinson, F.R.S. (Second Paper.)

On the Manufacture of Steel and the mode of Working it, by D. Chernoff; translated by Mr. William Anderson. (Reprinted.)

On the Docks and Railway Approaches at Barrow-in-Furness; by Mr. F. C. Stileman.

On the Steam-Ship "City of Rome"; by Mr. James Humphrys.

On the Hæmatite Iron Mines of the Furness District; by Mr. J. L. Shaw.

On the Manufacture of Jute; by Mr. William Fleming.

On the Steel-Compressing arrangements at the Barrow Works; by Mr. Alfred Davis.

On a new Reversing and Expansive Valve-Gear; by Mr. David Joy.

On a Standard Gauge for High Pressures; by M. George Marié.

On Recent improvements in the Machinery for Preparing and Spinning Cotton; by Mr. Eli Spencer.

On Implements and Machinery for Cultivating Land by Horse-power; by Mr. W. R. Bousfield.

The attendances at the Meetings have been very satisfactory. There were at the Annual General Meeting 110 Members and 63 visitors; at the Spring Meeting 73 Members and 73 visitors; at the Summer Meeting 164 Members and 67 visitors; and at the Autumn Meeting 67 Members and 66 visitors.

The thanks of the Members are due to the friends of the Institution in Barrow and the neighbourhood for their exertions in reference to the Summer Meeting of the Institution, and for the pleasure given to the Members by their visits to the New Docks, the Steel Works, the Shipbuilding Works (where the *City of Rome* was inspected), and other important works in Barrow, and also to the principal blast furnaces and hæmatite iron mines in the Furness district.

The Meeting terminated with a pleasurable trip to Windermere, when, as well as on the previous excursions, the Members received very hospitable entertainment.

In accordance with the Rules of the Institution, the President, two Vice-Presidents, and five Members of Council in rotation, go out of office this day. The result of the ballot for the election of the Council for the present year will be reported to the Meeting.

APPENDIX I.

Dr. ACCOUNT OF EXPENDITURE AND RECEIPTS

Expenditure.				£	s.	d.
To Printing and Engraving Proceedings of 1880	687	3	9			
" Reprinting former Proceedings	42	19	6			
	730	3	3			
Less Authors' Copies of Papers, repaid	52	14	8	677	8	7
" Stationery, Binding, and General Printing				187	8	1
" Rent				550	0	0
" Salaries and Wages				1147	11	0
" Coals, Firewood, and Gas				8	15	0
" Fittings and Repairs				27	3	2
" Postages				197	5	10
" Insurance				3	7	9
" Travelling Expenses				19	19	8
" Petty Expenses				48	3	8
" Meeting Expenses—						
Printing	43	9	2			
Translating	13	13	0			
Reporting	67	15	10			
Diagrams, Screen, &c.	17	8	7			
Travelling and Incidental Expenses	78	6	1	220	12	8
" Research				121	19	4
" Books purchased				115	13	1
Balance, being excess of Receipts over Expenditure				760	3	9
				£4,085	11	7

Dr. BALANCE SHEET,

	£	s.	d.
Capital of the Institution at this date	13,164	9	5
	£13,164	9	5

(*Signed*) EDWARD A. COWPER
THOMAS R. CRAMPTON } *Finance Committee.*
GEORGE B. RENNIE

APPENDIX I.

FOR THE YEAR ENDING 31st DECEMBER 1880. *Cr.*

Receipts.				£	s.	d.
By Entrance Fees—						
67 New Members at £2	134	0	0			
3 New Associates at £2	6	0	0			
12 New Graduates at £1	12	0	0			
2 Graduates transferred to Members at £1	2	0	0	154	0	0
,, Subscriptions for 1880—						
991 Members at £3	2,973	0	0			
22 Associates at £3	66	0	0			
54 Graduates at £2	108	0	0			
2 Graduates transferred to Members at £1	2	0	0	3,149	0	0
,, Subscriptions in arrear—						
44 Members at £3	132	0	0			
2 Graduates at £2	4	0	0	136	0	0
,, Subscriptions in advance—						
10 Members at £3	30	0	0			
1 Graduate at £2	2	0	0	32	0	0
,, Donations—						
Legacy from the late Robert Napier	100	0	0			
Other Donations	22	1	0	122	1	0
,, Interest—						
From Investments	351	8	6			
From Bank	18	1	7	369	10	1
,, Reports of Proceedings—						
Extra Copies sold				123	0	6
				£4,085	11	7

AS AT 31st DECEMBER 1880. *Cr.*

				£	s.	d.
By Cash—*In Bank*	346	11	5			
In Secretary's hands	250	0	0	596	11	5
,, Investments—						
£3,178 London & N. W. Ry. 4% Debenture Stock						
£2,200 North Eastern ,, ,, ,, ,,						
£1,800 Midland ,, ,, ,, ,,						
£1,800 Great Western ,, ,, ,, ,,						
£8,978	*cost*			8,868	4	11
Note—The Market Value of these investments at 31st Dec. 1880 was £10,300						
,, Subscriptions in Arrear				334	0	0
,, Office Furniture and Fittings				350	0	0
,, Library and Proceedings				2,615	13	1
,, Drawings, Engravings, Models, Specimens, and Sculpture				400	0	0
				£13,164	9	5

Audited and Certified by

ROBERT A. McLEAN & Co., Auditors, 8 Old Jewry, London.

APPENDIX II.

NAPIER BEQUEST.

Theory of the Steam Engine, by Pambour.
Engineering Precedents for Steam Machinery, by B. F. Isherwood.
Experimental Researches in Steam Engineering, by B. F. Isherwood.
Allgemeine Maschinenlehre, by M. Rühlmann. (4 vols.)
Treatise on Valve Gears, by G. Zeuner.
Practical Treatise on the Steam Engine, by A. Rigg.
Steam, Air, and Gas Engines, by J. Bourne.
Expériences des Machines à Feu, by V. Regnault.
Puissance motrice du Feu, by S. Carnot.
Wood-Working Machines, by J. Richards.
British Manufacturing Industries, by G. P. Bevan. (14 vols.)
Steam Engine, considered as a Heat Engine, by J. H. Cotterill.
Descriptive History of the Steam Engine, by R. Stuart.
The Indicator and Dynamometer, by T. J. Main and T. Brown.
Warming and Ventilating of Buildings, by C. Hood.
Warming and Ventilation of Buildings, by C. J. Richardson.
Warming and Ventilating of Buildings, by T. Tredgold.
Manufacture and Distribution of Coal Gas, by S. Clegg.
Technical Valuation, Purification, and Use of Coal Gas, by W. R. Bowditch.
Canal and River Engineering, by D. Stevenson.
Design and Construction of Harbours, by D. Stevenson.
Steam and Steam Navigation, by J. Scott Russell.
Construction navale, by J. A. Normand.
Architecture navale, by Wazon.
Manual of Naval Architecture, by W. H. White.
Our Ironclads, by E. J. Reed.
Theory of Vessels, by L. Euler; Translated by H. Watson.
Railroads and Carriages, by T. Tredgold.
Locomotive Engineering and Mechanism of Railways, by Z. Colburn.
Railway Engineering: Permanent Way, Rolling Stock, &c., by C. Couche.
Chemins de fer en Amérique, by Lavoinne and Pontzen.
Construction des Chemins de fer en temps de Guerre, by Lessar.
Practical Treatise on Railroads, by N. Wood.
Construction of Wrought-Iron Bridges, by J. H. Latham.
Stabilité des Revêtements et de leur Fondations, by Poncelet.
Iron Bridges and Roofs, by A. Ritter.

Boiler and Factory Chimneys, by R. Wilson.
Crumlin Viaduct, by H. N. Maynard.
Long Span Railway Bridges, by B. Baker.
Practical Treatise on Bridge Building, by S. Whipple.
Strength of Limes, Cements, Mortars, &c., by C. W. Pasley.
Mortars and Cements, by L. J. Vicat.
The Manufacture and Uses of Portland Cement, by H. Reid.
Civil Engineering in America, by D. Stevenson.
Gwilt's Encyclopædia of Architecture, by W. Papworth.
Manual of Hydrology, by N. Beardmore.
Report upon the Mississippi River, by Capt. Humphreys.
Hydraulic Tables, Coefficients, and Formulæ, by J. Neville.
Wasserhaltungs-Maschinen der Bergwerke, by J. Ritter von Hauer.
Hydraulics of Great Rivers, by J. J. Révy.
Water Wheels and Hydraulic Motors, by Bresse.
Turbine-Fourneyron, by Dobronravoff.
Sanitary Engineering, by B. Latham.
Metallurgy: Fuel, Copper, Lead, Silver and Gold, by J. Percy.
Elementary Treatise on Iron Metallurgy, by S. B. Rogers.
Elements of Geology, by Sir C. Lyell.
Principles of Geology, by Sir C. Lyell.
The Blast Furnace, by C. Schinz; translated by W. H. Maw, and M. Muller.
Mécanique chimique, by Berthelot.
Mechanical and Physical Properties of Copper-Tin alloys, by R. H. Thurston.
Exploitation des Mines, by A. Burat.
Etude sur l'emploi de l'Acier, by J. Barba.
Management of Steel, by G. Ede.
Manufacture of Steel, by M. L. Gruner.
Treatise on Metallurgy, by F. Overman.
Papers on Iron and Steel, by D. Mushet.
Nouvelles Expériences sur le Tirage des Voitures, by J. Morin.
Nouvelles Expériences sur le Frottement, by J. Morin.
Mécanique pratique, by J. Morin and H. Tresca.
Mechanical Principles of Engineering and Architecture, by H. Moseley.
Principles of Mechanism, by R. Willis.
Application de la Mécanique, by Navier.
Manuel de Mécanique appliquée, by V. Dwelschauvers.
Programme des Cours de Mécanique appliquée, by V. Dwelschauvers.
Der Constructeur, by F. Reuleaux.
Principien der Mechanik und Maschinenbaues, by E. Redtenbacher.
On the Strength of Materials, by P. Barlow.
Theory of Strains in Girders and similar structures, by B. B. Stoney.

Cours de Résistance appliquée, by V. Contamin.
Résistances et autres Propriétés de la Fonte, du Fer, et de l'Acier, by G. H. Love.
Festigkeit und Dimensionenberechnung, by J. J. Weyrauch.
Beiträge zur Kenntniss der elastischen Nachwirkung, by H. Streintz.
Treatise on Heat, by G. Zeuner.
Theory of Heat, by J. C. Maxwell.
Contributions to Molecular Physics in the domain of Radiant Heat, by J. Tyndall.
Sound, by J. Tyndall.
Lightning Conductors, by R. Anderson.
Units and Physical Constants, by J. D. Everett.
Application of Physical Forces, by A. Guillemin.
Dictionnaire des Arts et Manufactures, by C. H. Laboulaye.
Manual of Civil Engineering, by W. J. M. Rankine.
Useful Rules and Tables, by W. J. M. Rankine.
Ure's Dictionary of Arts, Manufactures, and Mines, by R. Hunt.
Cotton Manufacture of Great Britain, by A. Ure. (2 vols.)
Philosophy of Manufactures, by A. Ure.
Cyclopædia of Useful Arts and Manufactures, by C. Tomlinson.
Lives of the Engineers, by S. Smiles. (4 vols.)
Life of James Watt, by P. Muirhead.
Abstract of Patent Cases, by T. M. Goodeve.
Repertorium der technischen Literatur, by Bruno Kerl.
German Dictionary (Flügel's), by C. A. Feiling, A. Heimann, and J. Oxenford.
Italian Dictionary (Baretti's), by J. Davenport and Comelati.
Spanish Dictionary (Neuman and Baretti's), by D. M. Seoane.
The Handy Royal Atlas, by A. Keith Johnston.
Physical Atlas of Natural Phenomena, by A. Keith Johnston.

LIST OF DONATIONS TO THE LIBRARY.

Principles and Practice of Colliery Ventilation, by Alan Bagot; from the author.
La Locomotive sans Foyer, by Léon Francq; from the author.
The Agricultural Implement Trade, by James Howard; from the author.
Report of the Kew Committee, 1879; from Mr. G. M. Whipple.
Barometer and Sunshine, by G. M. Whipple; from the author.
Sunshine and Solar Radiation, by G. M. Whipple; from the author.
Annales Industrielles, 1879 (text and plates); from Mr. Henry Chapman.
Congrès international de la Propriété industrielle; from Mr. Henry Chapman.

Royal Indian Engineering College Calendar for 1880; from the College.
Wood-Working Machinery, by M. Powis Bale; from the author.
Life of Isambard Kingdom Brunel, by Isambard Brunel; from Mr. H. M. Brunel.
Trials of Westinghouse and Vacuum Continuous Brakes, by George Marié; from the author.
Sewage Disposal, by Henry Robinson: from the author.
Report on Technical Education, 1878; from the Livery Companies' Committee.
Matériel des Industries du Cuir, by J. P. Damourette; from Mr. Henry Chapman.
Chemins de fer devant le Parlement, by E. Level; from Mr. Henry Chapman.
Manuel des Ressorts en Acier, by M. Phillips; from Mr. Henry Chapman.
Les Aréomètres Baume, by P. Delahaye; from Mr. Henry Chapman.
Habitations de la Population Ouvrière, by E. Vuillemin; from Mr. Henry Chapman.
Car-Builders' Dictionary, by M. N. Forney; from the author.
Winding and Overwinding at Collieries, by C. M. Percy; from the author.
Society of Engineers, Inaugural Address of the President, Joseph Bernays; from Mr. Joseph Bernays.
Steel, its History, Manufacture, and Uses, by J. S. Jeans; from the author.
Report of American Railway Master Mechanics' Association; from the Association.
Report of Manchester Association of Employers &c., and Paper on the Locomotive of 1879, by T. Daniels; from the Association.
Mechanical Theory of Heat, by R. Clausius; from Mr. Walter R. Browne.
McKean's Rock-Boring Machinery; from Messrs. P. & W. Maclellan.
List of Indian Public Works Department; from the Department.
Treatise on the Screw Propeller, by John Bourne; from Mr. James Walton.
American and European Railway Practice, by A. L. Holley; from Mr. James Walton.
Girder Making and Bridge Building, by Edward Hutchinson; from the author.
Catalogue of Models at South Kensington Museum; from Mr. H. Sandham.
Geometrical examination of various Valve-Gears (text and plates); from the Industrial Society of the North of France.
Der Ingenieur, 1860 and 1868, by J. Weisbach; from Mr. Druitt Halpin.
Railway Economy, by D. Lardner; from Mr. Druitt Halpin.
Tables of Logarithms, by L. Schrön; from Mr. Druitt Halpin.
Library Catalogue of the Société des Ingénieurs Civils; from the Society.
Engineers' and Contractors' Book of Prices; from Messrs. Spon.
Bau-Constructions-Lehre, by W. Frauenholz; from the author.
Caxton Celebration Catalogue, 1877, by G. Bullen; from Mr. E. A. Cowper.
Works in Iron—Bridge and Roof Structures, by Ewing Matheson; from the author.
Aid Book to Engineering Enterprise Abroad, by Ewing Matheson; from the author.
Report on the Irrawaddy River, Parts 1-4, by Robert Gordon; from the author.

Winding and Overwinding at Collieries, 3rd ed., by C. M. Percy; from the author.

Handbook on House Property, by E. L. Tarbuck; from the author.

Van Nostrand's Engineering Magazine, 1880, Vol. 22, Nos. 1–5; from Mr. D. Van Nostrand.

Turbines and Turbine Pumps (text and plates), by C. A. Ångström; from the author.

The Land Question, by Thomas Aveling; from the author.

Admiralty Trials of Screw Ships; from the Admiralty.

Tredgold's Principles of Carpentry; from Mr. W. Carpmael.

Tredgold on the Strength of Cast Iron; from Mr. W. Carpmael.

Locomotive Engines upon Railways, by Chev. de Pambour; from Mr. W. Carpmael.

Nouveaux Appareils pour Wagons de Secours, by Ferdinand Mathias; from the author.

Machines à Percer et à Tarauder, by Ferdinand Mathias; from the author.

Guide du Mécanicien Constructeur et Conducteur de Machines Locomotives, by L. le Chatelier, E. Flachat, &c.; from Mr. Henry Chapman.

Heat as a Mode of Motion, by John Tyndall; from the author.

Six Lectures on Light, by John Tyndall; from the author.

Notes of Lectures on Light, by John Tyndall; from the author.

Lessons in Electricity, by John Tyndall; from the author.

Faraday as a Discoverer, by John Tyndall; from the author.

English-Dutch and Dutch-English Dictionary (2 vols.), by H. Picard; from Mr. William Walker.

Teeth of Wheels, by M. Camus (translated by J. I. Hawkins); from Mr. William Walker.

Elementary Treatise on Hydrostatics, by Richard Potter; from Mr. William Walker.

Strength of Cast Iron and other Metals, by Thomas Tredgold; from Mr. William Walker.

Journal of the Royal Dutch Institute of Engineers; from Mr. William Walker.

Molesworth's Metrical Tables; from Mr. Guilford L. Molesworth.

Windverstrebung eiserner Brücken und Brückenpfeiler, by H. Zimmermann; from the author.

Whitworth Measuring Machine, by T. M. Goodeve and C. P. B. Shelley; from Prof. T. M. Goodeve.

Russian - French - German - English and English - Russian - French - German Dictionary (2 vols.), by C. P. Reiff; from Mr. John W. Davison.

Steam-Ship Capability, by C. Atherton; from Mr. John W. Davison.

Struve's Double Stars, by Lord Lindsay; from the author.

Mauritius Expedition, 1874, by Lord Lindsay; from the author.

As Estradas de Ferro do Brazil em 1879 (with map), by F. P. Passos; from Mr. Charles Neate.

Économie du Combustible, by E. Bède; from Mr. Henry Chapman.

Chaînes forgées sans Soudures en Acier ou en Fer, by David and Damoizeau; from Mr. Henry Chapman.

Système de Porte-Outils mobile volant, by E. P. Baville; from Mr. Henry Chapman.

Communications électriques permanentes des Trains en Marche, by E. de Baillehache; from Mr. Henry Chapman.

Nouvelles formes de Piston, by P. Giffard; from Mr. Henry Chapman.

Conservation des Bois au Sulfate de Cuivre, by A. Legé and Fleury-Pironnet; from Mr. Henry Chapman.

Conférences à l'Association Polytechnique—le Pont du Rhin, et le Tunnel des Alpes, by A. Perdonnet; from Mr. Henry Chapman.

Contre-poids appliqués aux Roues Motrices des Machines Locomotives, by C. Couche; from Mr. Henry Chapman.

Application du Frottement de Roulement aux Boîtes et Fusées d'Essieux des Véhicules des Chemins de fer, by J. B. Vidard; from Mr. Henry Chapman.

Organisation de l'Enseignement Industriel et de l'Enseignement Professionel, by A. Morin and H. Tresca; from Mr. Henry Chapman.

Droit des Inventeurs, by É. Barrault; from Mr. Henry Chapman.

Corps des Mines, Notices relatives à l'Exposition universelle en 1878; from Mr. Henry Chapman.

Calcul des Diamètres des Cônes de Transmission, by F. Mathias; from Mr. Henry Chapman.

Chaudières à Bouilleurs inférieurs et à Réchauffeurs latéraux, by North of France Steam Boiler Association; from Mr. Henry Chapman.

Frein à Embrayage automatique, by R. Bourgougnon; from Mr. Henry Chapman.

Frein à Embrayage automatique (another edition), by R. Bourgougnon; from Mr. Henry Chapman.

Contrôleur Brunot de la Marche des Trains, by R. Vion; from Mr. Henry Chapman.

Travail absorbé par la Filature de Lin, by E. Cornut; from Mr. Henry Chapman.

Procédés et Applications du Chauffage par Gazogènes, by A. Fichet and S. Périssé; from Mr. Henry Chapman.

Servo-Moteur Farcot et ses applications, by É. Barrault; from Mr. Henry Chapman.

Brasserie, Maltage pneumatique, by N. Galland; from Mr. Henry Chapman.

Voitures à Deux Étages pour Chemins de fer de MM. Bournique et Vidard, Report by M. A. Baude; from Mr. Henry Chapman.

Voitures à Deux Étages pour Chemins de fer de MM. Bournique et Vidard, Report by Commission of Inventions; from Mr. Henry Chapman.

Transmission pneumatique des Dépêches, by MM. Mignon and Rouart; from Mr. Henry Chapman.

Signaux-Disques sans Contre-poids, et Lanternes sans Poulies ni Chaînes, by J. Baranowski; from Mr. Henry Chapman.

Injecteur Automoteur, by H. Giffard; from Mr. Henry Chapman.

Théorie de l'Injecteur Automoteur de M. H. Giffard, by M. Reech; from Mr. Henry Chapman.

Marine Boilers of the United States, by B. H. Bartol; from Mr. James A. C. Hay.

Gunpowder Manufacture, by James A. C. Hay; from the author.

Manufacture of Iron, by F. Overman; from Mr. James A. C. Hay.

Marine-Engine Construction and Classification, by C. Atherton; from Mr. James A. C. Hay.

Turning and Mechanical Manipulation (3 vols.), by C. Holtzapffel; from Mr. James A. C. Hay.

United States Survey of Idaho and Wyoming, by F. V. Hayden; from the author.

Manufacture and Distribution of Coal Gas, by William Richards; from Mr. Michael M. Brophy.

Dynamo-Electric Current, by C. William Siemens; from the author.

Self-Acting Continuous Railway Brakes, by F. T. Haggard; from the author.

Protection of Life from Machinery, by William Watson; from the author.

Public Works at Philadelphia Centennial Exhibition, by William Watson; from the author.

Corporation, its Benefits and Evils, by Simon Sterne; from the author.

Sections of Rolled Iron Joists and Girders; from Messrs. Measures Bros.

Catalogue of Wood-Working Machinery; from Messrs. S. Worssam & Co.

Catalogue of Corrugated-Iron Roofs and Fencing; from Messrs. J. Arthur Young & Co.

Prospectus of Royal Technical College, Hannover; from the College.

Workshop Appliances, by Charles P. B. Shelley; from the author.

Shooting Diagram of Whitworth and Martini-Henry Rifles; from Sir Joseph Whitworth.

Catalogue of Wood and Stone Working Machinery; from Messrs. Max Western & Co.

Horloges, Armes, et Appareils scientifiques, exposés à Bruxelles, 1880, by M. Gérard; from the author.

Rudimentary Treatise on Masonry and Stone Cutting, by Edward Dobson; from Mr. Druitt Halpin.

Treatise on the Mathematical Theory of the Steam Engine, by T. Baker; from Mr. Druitt Halpin.

Treatise on Limes, Cements, Mortars, Concretes, &c., by G. R. Burnell; from Mr. Druitt Halpin.

Rudimentary Treatise on Steam Boilers, by R. Armstrong; from Mr. Walter R. Browne.

Rudimentary Treatise on Tubular and other Bridges, by G. D. Dempsey; from Mr. Walter R. Browne.

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Proceedings of the Industrial Society of St. Quentin; from the Society.

Proceedings of the Industrial Society of Mulhouse; from the Society.

Proceedings of the Industrial Society of the North of France; from the Society.

Proceedings of the Saxon Society of Engineers and Architects; from the Society.

Proceedings of the Swedish Society of Engineers; from the Society.

Journal of the Norwegian Polytechnic Society; from the Society.

Journal of the Franklin Institute; from the Institute.

Transactions of the American Society of Civil Engineers; from the Society.

Transactions of the American Institute of Mining Engineers; from the Institute.

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Report of the Sassoon Mechanics' Institute, Bombay; from the Institute.

Proceedings of the Institution of Civil Engineers; from the Institution.

Journal of the Iron and Steel Institute; from the Institute.

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Transactions of the Institution of Civil Engineers of Ireland; from the Institution.

Transactions of the North of England Institute of Mining and Mechanical Engineers; from the Institute.

Proceedings of the South Wales Institute of Engineers; from the Institute.

Transactions of the Institution of Engineers and Shipbuilders in Scotland; from the Institution.

Transactions of the Midland Institute of Mining, Civil, and Mechanical Engineers; from the Institute.

Proceedings of the Cleveland Institution of Engineers; from the Institution.

Transactions of the West of Scotland Mining Institute; from the Institute.

Proceedings of the Royal Society of London; from the Society.

Proceedings of the Royal Society of Edinburgh; from the Society.

Proceedings of the Royal Institution; from the Institution.

Transactions of the Institution of Surveyors; from the Institution.

Proceedings of the Association of Municipal and Sanitary Engineers and Surveyors; from the Association.

Journal of the Royal United Service Institution; from the Institution.

Papers of the Royal Engineer Institute; from the Institute.

Proceedings of the Royal Artillery Institution; from the Institution.

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Transactions of the Institution of Naval Architects; from the Institution.

Transactions of the Royal Institute of British Architects; from the Institute.

Report of the British Association of Gas Managers; from the Association.

Proceedings of the Physical Society of London; from the Society.

Proceedings of the Literary and Philosophical Society of Manchester; from the Society.

Report of the Manchester Geological Society; from the Society.

Journal of the Royal Scottish Society of Arts; from the Society.

Proceedings of the Philosophical Society of Glasgow; from the Society.

Transactions of the Royal Irish Academy; from the Academy.

Journal of the Liverpool Polytechnic Society; from the Society.

Journal of the Society of Arts; from the Society.

Reports of the Manchester Steam Users' Association; from Mr. Lavington E. Fletcher.

Report of the Boiler Insurance and Steam Power Company; from Mr. Niel McDougall.

Report of the National Boiler Insurance Company; from Mr. Henry Hiller.

Report of the Liverpool Free Public Library and Museum; from the Committee.

The Engineer; from the Editor.

Engineering; from the Editor.

Iron; from the Editor.

The Mining Journal; from the Editor.

The Railway Record; from the Editor.

The Colliery Guardian; from the Editor.

The Iron and Coal Trades Review; from the Editor.

Ryland's Iron Trade Circular; from the Editor.

Revue générale des Chemins de fer; from the Directors.

Milan Polytechnic Journal (Il Politecnico); from the Editor.

Annales des Travaux Publiques; from the Proprietors.

The Railroad Gazette; from the Editor.
The Railway Engineer; from the Editor.
The Engineering and Mining Journal; from the Editor.
The Telegraphic Journal and Electrical Review; from the Editor.
The Fireman; from the Editor.
The Universal Engineer; from the Editor.
The Marine Engineer; from the Editor.
The Contract Journal; from the Editor.
The Machinery Market; from the Editor.

The PRESIDENT moved the adoption of the Annual Report of the Council. The motion was carried unanimously.

The PRESIDENT announced that the Ballot Lists for the election of Officers had been opened by a committee of the Council, and the following Members of Council were found to be elected for the present year:—

PRESIDENT.

EDWARD A. COWPER, ...	London.

VICE-PRESIDENTS.

CHARLES COCHRANE, . . .	Stourbridge.
FRANCIS W. WEBB, ...	Crewe.

MEMBERS OF COUNCIL.

DAVID GREIG, ...	Leeds.
ARTHUR PAGET, ...	Loughborough.
RICHARD PEACOCK, . . .	Manchester.
SIR JAMES RAMSDEN, . . .	Barrow-in-Furness.
GEORGE B. RENNIE, . . .	London.

The Council for the present year would therefore be as follows:—

PRESIDENT.

EDWARD A. COWPER, ...	London.

PAST-PRESIDENTS.

SIR WILLIAM G. ARMSTRONG, C.B., D.C.L., LL.D., F.R.S., ...	Newcastle-on-Tyne.
FREDERICK J. BRAMWELL, F.R.S., .	London.
THOMAS HAWKSLEY, F.R.S., . .	London.
JAMES KENNEDY, ...	Liverpool.
JOHN RAMSBOTTOM, . . .	Alderley Edge.
JOHN ROBINSON, ...	Manchester.
C. W. SIEMENS, D.C.L., LL.D., F.R.S.,	London.
SIR JOSEPH WHITWORTH, BART., D.C.L., LL.D., F.R.S., ...	Manchester.

VICE-PRESIDENTS.

I. LOWTHIAN BELL, F.R.S., . .	Northallerton.
CHARLES COCHRANE, . . .	Stourbridge.
JEREMIAH HEAD, ...	Middlesbrough.
CHARLES P. STEWART, . . .	Sunninghill.
FRANCIS W. WEBB, ...	Crewe.
PERCY G. B. WESTMACOTT, . .	Newcastle-on-Tyne.

MEMBERS OF COUNCIL.

DANIEL ADAMSON, ...	Manchester.
WILLIAM ANDERSON, . . .	London.
THOMAS R. CRAMPTON, . . .	London.
EDWARD EASTON, ...	London.
DAVID GREIG, ...	Leeds.
J. HAWTHORN KITSON, . . .	Leeds.
WILLIAM MENELAUS, . . .	Dowlais.
ARTHUR PAGET, ...	Loughborough.
RICHARD PEACOCK, ...	Manchester.
JOHN PENN, ...	London.
SIR JAMES RAMSDEN, . . .	Barrow-in-Furness.
GEORGE B. RENNIE, . . .	London.
WILLIAM RICHARDSON, . . .	Oldham.
JOSEPH TOMLINSON, JUN., . .	London.
R. PRICE WILLIAMS, . . .	London.

The PRESIDENT said he felt greatly honoured by being elected for a second year. Although the duties were somewhat arduous, he was happy to devote himself as far as possible to the interests of the Institution. The only condition was that which he had mentioned in the first instance—that the Members would give support to the chair. It was only by conducting their affairs in a proper and a regular manner that it was possible for an Institution like this to flourish. The example of many years past was quite sufficient to encourage them in going forward, and adding to their numbers more and more.

The Institution was becoming more appreciated on the Continent, in America, and elsewhere, as the first Institution of the world in regard to mechanical engineering; and he hoped it would continue to occupy that proud position, and would go on prospering and to prosper.

The PRESIDENT wished to remind the members that the Summer Meeting would be held at Newcastle-on-Tyne, as had been arranged at the time of the meeting at Barrow. They would all agree that that had been a very satisfactory meeting, and there was every reason to believe that the meeting at Newcastle would be even better than anything that had gone before. A local committee had been formed, consisting of a large number of influential gentlemen; and he was happy to say that their friend Mr. Westmacott was chairman of that committee. He was sure the members would meet with a very hearty reception, and would have an immense number of works, mines, &c., to visit; and therefore he hoped they would assemble at Newcastle, on Tuesday 2nd August, in great numbers.

Before proceeding to the reading of the papers on the list, which he believed would be found of much interest, he wished to express the hope that the members would discuss them in a thorough manner, and would not be afraid of expressing their opinions. He had been a little disappointed at the Manchester meeting, because after some trouble they had succeeded in getting there a paper on a Manchester subject, namely "Cotton Manufacture." If that subject was ever to be discussed anywhere by the engineers of the country, it ought to be discussed in Manchester; and the paper read was a very good one; but he was sorry to say that the discussion had altogether disappointed him. He had himself taken a great deal of trouble with personal friends to get cotton manufacturers and manufacturers of machines for cotton to attend the meeting, and they did attend; but he was sorry to say they did not open their mouths, so that the meeting had not had the benefit of the opinions of Manchester men on a Manchester manufacture. On the present occasion the subjects

brought forward were of a more varied character, and he hoped there would be an ample and a lively discussion upon them.

The following papers were then read and discussed:—

On Harvesting Machinery; by Mr. Ernest Samuelson, of Banbury.

On the Various modes of Transmitting Power to a distance; by M. Arthur Achard, of Geneva.

The Meeting was then adjourned to the following day.

The Adjourned Meeting of the Institution was held at the Institution of Civil Engineers, London, on Friday, 28th January, 1881, at Three o'clock p.m.; Edward A. Cowper, Esq., President, in the chair.

The following papers were read and discussed:—

On Machines for producing Cold Air; by Mr. T. B. Lightfoot, of Dartford.

On Stone-Dressing Machinery; by Mr. J. Dickinson Brunton and Mr. F. Trier, of London.

On the Farquhar Filtering Apparatus; by Mr. Henry Chapman, of London.

The President proposed a vote of thanks to the Institution of Civil Engineers for their kindness in granting their rooms for the meeting, which was carried unanimously.

The Meeting then terminated.

ON HARVESTING MACHINERY.

By Mr. ERNEST SAMUELSON, of Banbury.

In a paper read before the Manchester meeting of this Institution by Mr. W. R. Bousfield (Proceedings, October 1880, p. 529), the operations of agriculture were divided into four chief divisions, as follows:—

1. Preparation of the land.
2. Sowing of the seed.
3. Harvesting of the crops.
4. Preparation of the crops for consumption.

The writer proposes to take for his subject the third division, and, without going into the history of the question, to discuss some of those machines which are in practical use in the country at the present date.

Harvesting machines may be divided into two main classes, as follows:—

(1) Those in use for cutting and gathering hay crops, whether of natural or of artificial grasses;

(2) Those designed for the harvesting of corn crops.

The first division may be subdivided into three classes:—

(*a*) Machines used for cutting down the standing grass; or Mowing Machines.

(*b*) Those used for spreading the cut grass, in order to expose it to the influence of the sun and wind; or Haymakers.

(*c*) Those which are used for gathering the spread crop; or Horse Rakes.

As time will not permit of the latter two subdivisions being included in this paper, the writer intends to confine himself on this occasion to the first, or mowing machines.

Mowing Machines.

A Mowing Machine consists of three main parts:—

(1) The cutting apparatus, which travels close to the ground, generally carried on a wheel at each end;

(2) A frame containing the gearing which puts the cutting apparatus in motion;

(3) The two main wheels, which support the frame, and by their adhesion furnish the motive power to the gearing.

The arrangement generally adopted for these three parts is that shown in Figs. 1, 7, and 8, Plates 1*C* and 2, which represent two of the ordinary forms of mowers.* Other arrangements of the parts, such as placing the cutter-bar B in front of and between the main travelling wheels W W, are occasionally proposed in theory, but seldom or never employed in practice.

The pole or shaft P, by which the horses are attached to the machine, is generally fixed by means of a "pole bracket" to the axle of the travelling wheels, and turns freely upon that axle; in many cases the draught is taken direct from the main axle, but in some it is taken partly from the axle and partly from the main frame itself.

Cutting Apparatus.—The transmission of the motion to the cutting apparatus is effected generally in one of two ways. In the first case, Figs. 1, 7, and 8, one or both of the main wheels W have an internal ring of teeth, into which gears one or a pair of pinions, which are carried on a first-motion shaft S, and transmit their motion to it by means of ratchet-boxes and pawls. They thus convey motion to the cutting apparatus only when the machine is moving forward, the wheels revolving independently when the machine is being turned or moved backwards. On the first-motion shaft S runs loose a bevel wheel N, which gears into a bevel pinion keyed on a longitudinal inclined shaft. On the front end of this shaft is fixed a crank disc D, and a connecting-rod is used to couple this crank with the horizontal reciprocating knife K. Clutch gear is generally used for throwing the bevel wheel N in and out of gear with the shaft S.

* Plate 1*A* gives a perspective view of the mower, Fig. 1, showing the general arrangement.

In the second method of obtaining the requisite motion for the knife, Fig. 3, Plate 1*C*, the travelling wheels W transmit their forward motion to the main axle A itself, through ratchet-boxes and pawls, and thence to such a train of gearing as is necessary to obtain the proper speed for the knife K. This class of machine is used chiefly in cutting artificial grasses, which are not so difficult to deal with as natural meadow grass; and also where the crops are light. The chief advantage of this method of driving is that it enables the whole of the gearing to be completely boxed or covered in, and so protected from dirt; on the other hand such machines are much heavier in draught, owing to the point of application of the power being so much nearer to the centre of the axle.

The cutting apparatus consists of a flat bar (made in America of cold rolled iron, but in England of steel), to which are attached a set of pointed projections or fingers F, having a horizontal slot or space cut across them; and in this slot the knife or sickle K is caused to reciprocate, as shown in Figs. 4 and 5, and in section in Fig. 9, Plate 2.

The fingers are made in various forms, either of the open or solid pattern, both of which are shown in Figs. 4 and 5, Plate 1*C*. In the latter the sickle or knife K runs upon the cutter-bar B; whilst in the former it runs upon a kind of open framework, formed by the fingers F themselves, which allows the dirt and short pieces of grass, moss, &c., to be worked out by the movement of the knife.

Fingers are made of chilled cast iron, malleable cast iron with steel plates riveted on for cutting edges, wrought iron with riveted steel plates, and a combination of welded iron and steel.

The cast iron have almost gone out of date, having been superseded by the latter forms. In the second and third varieties, the steel plate is riveted on to the bottom face of the slot; the objection however to this form is the liability of the plate to become loose. With the welded iron and steel fingers, the steel plate, instead of being riveted, is welded on to the wrought iron, in some cases on both the top and bottom of the slot, as in Bamlett's finger, the pile for which is shown in Fig. 6, Plate 1*C*. Another method is that employed by Messrs. Samuelson & Co., where the fingers are piled or built up in the following manner, as shown in Fig. 4. A

square bar *a* of wrought iron is taken, and another small piece of iron *b*, about 4 in. in length, is welded on at one end, and drawn down to a point, forming a V shaped pile. Between the ends of these two pieces is laid transversely a short piece of round iron *c*, and one end of the jaw is closed over it; and then upon each side of the pointed end is welded a small steel plate *d*. The pile thus formed is brought up to a welding heat, and placed in a pair of dies under a stamp, and the necessary shape is thus given to the finger. When it leaves the dies it goes to a pair of fraying tools, and from thence to a circular saw, where the slot *e* is cut within which the sickle works; finally it is fitted to the beam or cutter-bar B, and hardened. By this process of manufacture a hard cutting edge is secured, whilst a soft core is maintained in the centre, as shown at *f*; and the core, being the first to wear, always leaves a flat surface for the sections or blades K of the knife to work upon. The grain of the iron runs in the direction of the point in the main body of the finger, and at right angles to this in the cross bar *c*; and this ensures the strain being taken up by the iron in the most advantageous manner.

The knife or sickle is composed of a number of steel triangular sections or blades K, Fig. 4, riveted upon an iron or steel bar or back G, Fig. 9, Plate 2. These steel sections are hardened in one or other of two ways: either uniformly throughout, and then tempered to such a degree as will admit of their being sharpened by a file; or else in such a manner as to leave a harder cutting edge of about $\frac{3}{8}$ in. along each side, the rest of the section being soft; in this case a grindstone is necessary to sharpen them.

On each end of the finger or cutter-bar B is fixed a shoe supported by a small wheel M, Plates 1*C* and 2, which can be adjusted so as to raise or lower the cutter-bar from the ground.

The method of attaching the beam or cutter-bar B to the main frame is either by a radial joint or shoe J, as in Figs. 1 and 2, Plate 1*C*; or through a wrought-iron connecting-link L, as in Figs. 7 and 8, Plate 2. On this latter or the "Buckeye" plan, means are provided for altering the angle of the fingers, or tipping their points downward, in order to creep under laid grass. In the combined mower and

reaper, Figs. 7 and 8, this is effected by a small tipping lever T, which is attached to the connecting-link *l*, as shown in Fig. 13, Plate 3. But it is of doubtful utility, as it entails complication, and is liable to cause the fingers and knife to become choked with dirt, and so stop the machine. The beam or cutter-bar B, being in either case attached to the main frame by a hinged connection, is capable of being turned up and held in a vertical position, for the purpose of travelling more easily along roadways, &c.

It is sometimes necessary to raise the beam B off the ground horizontally when at work, in order to pass over any obstruction; this is done by the driver from his seat, by means of a lifting handle Z and a quadrant Q, Fig. 10, over which passes a chain, a system of levers being used in order to sustain the weight of the beam. Two examples of the methods for securing this parallel lift are shown: namely in Fig. 10, Plate 3, which applies to the mower, Fig. 1; and in Fig. 11, which applies to the mower, Plate 2. In Fig. 10, when the chain C is tightened by means of the lever Z and quadrant Q, the beam B is stiffened by the bar A, to which the chain C is attached at E; when the chain is tightened, the curved underside of the bar A bears against the rib R on the shoe J, by which means the beam is lifted parallel from the ground. In Figs. 8 and 11, the stud S on the short lever J is brought into contact with an inclined plane I upon the underside of the wrought-iron connecting-link L. One end of this lever J is hinged to the main shoe Y, and to the other the lifting chain C is attached; and the pressure of the stud S against the inclined plane ensures the parallel lift of the beam B, at whatever angle it may be lying with respect to the axle of the main wheels.

When the machine has been once round the field and starts again, a clear track or path is necessary for the horse which walks round nearest to the standing crop, and for the travelling wheels; and this is provided for by hingeing to the off-side shoe, at the outer extremity of the cutter-bar or beam, a trackboard T, inclined inwards towards the main wheels, as in Fig. 1. To the tail of this board is fixed a round stick R, still more inclined inwards towards the wheels, so that, as the grass is cut and passes along the board, the stick turns it over and forms a swathe. The wheels and horses pass on each side of this swathe in making the following cut.

The tendency of all machines which have the cutter-bar placed in front of the main axle is for the beam to exert a pressure upon the ground, this being due to the downward direction of the power as transmitted from the travelling wheels, and also to the holding down of the beam by the grass. This downward pressure must be balanced in a well-designed machine, and Figs. 12 and 13, Plate 3, give methods employed for this purpose. In either method the draught is taken from a lug U below the axle, on the pole bracket G, through pulleys or levers so arranged that the pull tends to lift both the pole P and the frame F which carries the cutter-bar; and by properly proportioning the several leverages, the lifting tendency can be accurately adjusted to the required amount. These methods enable the beam to float, as it were, over the ground, but without rising from its work. In crossing steep ridge and furrow this is especially desirable; and either such arrangements must be employed, or else a third carrying wheel must be attached to the front of the main frame by means of a short pole, which lifts the beam as the machine rises up the ridge.

General Features of Design.—While lightness of construction is desirable, strength must not be sacrificed to this, because it is a very serious matter for the farmer if some part of the machine gives way under a sudden strain, to which this class of machine is particularly liable; such strains arising from obstructions on the surface of the ground, or from the knife and fingers being blunt or becoming clogged or choked up.

Again, the frame and gearing must not come within about 6 in. of the ground, otherwise it will disturb the cut swathe over which it is passing, and be liable to pick up some of the cut grass: for which reason it is also usual to cover in, as completely as possible, all rotating parts.

The width between the travelling wheels is generally about 3 ft., so that they shall run on each side of the swathe; and their average diameter is about 2 ft. 4 in. to 2 ft. 6 in. The width of the tread is about 4 in., and it is generally studded at intervals with projecting ribs or stucks, in order to obtain more adhesion. The distance in

plan between the pole P, Fig. 8, Plate 2, and the inner end of the beam or cutter-bar B should be as small as possible, without causing the horse on the off-side to walk in the standing grass. There is usually about 18 in. horizontal width from the centre of the pole to the first finger upon the beam; but when a mower is used for reaping, as is sometimes the case, the pole is placed about 2 ft. 4 in. from the first finger, otherwise the off-side whippletree breaks down the standing corn, whilst in the case of short grass it passes over.

The speed of the knife, without being excessive, should be sufficiently quick to maintain a clean sweet cut, and to clear itself from all loose dirt. The throw of the knife in mowing is about 3 in., and the distance between each pair of fingers is the same; each section or blade therefore travels from the centre of one finger to the centre of the next, and back again. But in reaping machines each section travels from the centre of one finger to the centre of the finger on either side, having thus a "double throw" of 6 in. The number of revolutions of the crank-wheel in a mowing machine is $3\frac{1}{2}$ to $3\frac{3}{4}$ for each foot advance of the machine; whilst in a reaper, owing to the double throw, the number is generally from $1\frac{1}{2}$ to 2 per foot.

Some mowing machines are designed with the cutter-bar lying to the rear of the main axle, the other principles of construction being much the same. With this plan difficulty is experienced when backing the machine, the tendency being to force the beam into the ground; also it is difficult for the driver to keep his attention fixed upon both the cutter-bar and the horses. This plan however is almost imperative when the machine is also to be used as a side-delivery self-raking reaper, as will be shown presently.

Reaping Machines.

We will now pass on to the second division, namely machines designed for harvesting corn, or Reaping Machines.

These may be subdivided into three types :—

(1) Those which deliver the cut crop at the back of the beam, as in a mower; or Back-delivery Reapers.

(2) Those which are provided with a platform at the back of the

beam, on which the cut crop falls, and is then raked off to the side of the machine by revolving rakes; or Side-delivery Reapers.

(3) Those which cut the crop, deliver it into suitable receptacles, bind it into sheaves, and deposit them on the ground; or Automatic Binders.

Back-delivery Reapers.—A reaper of this the first division is a much more simple piece of mechanism to deal with than a mower, because there are not the same difficulties to contend with in the case of dry crops or corn as of green crops or grasses. The speeds are consequently slower, the working parts fewer, and the strains not so severe.

The simplest of all reapers is the Manual Back-delivery, Fig. 18, Plate 5, in which a man has a seat R provided for him on the body of the machine, in front of the driver's seat attached at D, and using a short hand-rake collects the standing corn into the knife; where it is cut, and falls upon a slatted platform S, Figs. 14 and 16, Plate 4, which is hinged to the cutter-bar. This platform is held in an inclined position, as shown in Fig. 14, till sufficient corn is cut and collected to form a sheaf, when the man, by means of a foot-lever, allows the platform to drop backwards upon the ground; the sheaf is then deposited on the ground, the stubble assisting in raking it off the platform by projecting up between the slats of the platform, and thus acting like a comb. As soon as the sheaf is raked off, the platform is raised again into its inclined position, and a fresh sheaf is collected.

This form of platform may be attached to the cutter-bar of an ordinary two-wheeled mowing machine, and an extra seat fixed upon the main frame for the raker, just above the inside main-wheel; this, with a special off-side shoe, which will be described immediately, constitutes the arrangement of a Combined Mower and Manual Reaper. The mower shown in Fig. 1, and that shown in Figs. 7 and 8, can both be converted in this manner: but in Fig. 1 the pole bracket G is shifted bodily on the axle, so as to bring the horses further away from the standing corn; whilst in Figs. 7 and 8 the pole bracket G is fixed, and the pole P only is shifted from the side of the pole bracket marked "mower" to that marked "reaper" in Fig. 8. The speed of the knife either remains the same for both

operations, or it can be altered by substituting a larger first-motion pinion, or by other equivalent means.

The off-side shoe of a reaping machine differs in size and construction from that employed for mowing, because of the height of the corn and the difficulty in separating it. It carries dividing irons V, which project about 15 in. to 18 in. into the crop, in advance of the cutter, and thrust on one side the standing corn, so as to admit of a clear passage for the shoe and wheel, as shown in Fig. 14, Plate 4, and also in the plan, Fig. 25, Plate 8, and Fig. 26, Plate 9.

In the Automatic Back-delivery reaper, Fig. 16, Plate 4, the place of the raker is taken by a revolving reel, which is driven by suitable chain gearing G from the axle of the machine. This reel has three blades BB, which collect the corn on the slatted platform, and one rake R, which rakes the sheaf off. The platform S receives its dropping movement by means of a cam C and rod A, as shown also in Fig. 17.

The reaper pure and simple, that is, a machine intended to be employed as a reaper only, is carried on one broad main wheel at the near side, and supported by a small wheel fixed to the off-side shoe. The frame and gearing are carried by the main axle, and the beam or cutter-bar is bolted on to part of the main frame. The cutting parts, or fingers and knife, do not differ materially from those described in the mower, with this slight exception, that where the crops are very dry, as on some parts of the Continent and in America, the edges of the sections or blades are serrated, thereby causing a sawing action rather than a cutting one. The first motion is usually taken from a ring of teeth cast on, or attached to, the inside periphery of the travelling wheel; but in some cases from a spur wheel fixed on the main axle, as in the second class of mowers, Fig. 3, Plate 1*C*.

In a manual machine the gearing which drives the crank is very simple. In Fig. 18, Plate 5, is shown one of the simplest forms of this class, the gearing used being only a bevel wheel and pinion; this is one of the earliest iron-frame reapers manufactured in this country. In Figs. 21 and 22, Plate 6, is shown another simple form, which may be looked upon as a general type of this class of machine; here the pinion P has its inner face shaped as a clutch C, engaging with a pin

fixed in the end of the shaft, as shown in Fig. 23, and has only to be slid back far enough to disengage this clutch, as shown dotted in Fig. 23, without its teeth ever leaving those of the travelling wheel. In a still later modification the driver is able to tip the fingers downwards when necessary, so as to pick up laid portions of the crop. This machine resembles Fig. 16, but with a raker's seat, as shown dotted, instead of the automatic reel. The beam can also be lifted parallel from the ground, by means of a quadrant on the near side, and an adjustable axle-plate on the off-side shoe, as in Fig. 14, Plate 4; and further the beam can be turned up bodily about its inner end, so as to stand vertically for travelling.

In an automatic back-delivery reaper, as in a manual machine, it is necessary to tie up and remove the sheaves before being able to go round the field a second time; and this objection has led to the designing of the side-delivery machine.

Side-delivery Reapers.—In this class a quadrantal platform A is fixed on the back of the cutter-bar B, Figs. 24 and 25, Plates 7 and 8; and is suitably supported off the ground by stays. On the main body of the machine* is an upright shaft S, to which are fastened four or more rakes R. These are caused to revolve like the sails of a windmill, and, in so doing, gather the standing corn to the knife and then rake it backwards off the platform when cut, throwing it to one side behind the main travelling wheel W, and thus leaving a clear track for the horses on the following round.

Except where the crop is desired to be left in a swathe, as in the case of barley, it is usual to collect it in sufficient quantities to form a sheaf. The simplest method of doing this is to substitute for some of the rakes what are termed "gatherers," which only gather the standing crop to the knife, and then pass clear over the cut grain lying on the platform, which thus accumulates there until the next rake comes round and sweeps the sheaf off.

The methods by which these rakes are caused to travel round in the necessary path are various. One plan is to hinge the rakes R to the upright shaft S, as in Fig. 19, Plate 5, and to guide them from

* A perspective view of this machine is shown in Plate 1*B*.

another fixed point P by short rods. Another is to incline the rake-shaft S itself towards the platform A, as in Fig. 20, and to fix the rakes R to the shaft. In both these plans the platform A must be curved to suit the path of the rake; and this is objectionable, as in time the platforms are liable to lose their shape; and further, in the latter plan, the rakes do not enter and leave the crop at the proper angle, namely at right angles to the ground.

A third plan is to substitute a chain for the short guiding rod in Fig. 19, to make the platform flat, and to guide the rake over it by means of a cam path; but the more usual plan is to use a cam path alone, of suitable shape, as shown in the full-size models exhibited and in Figs. 24 and 25, Plates 7 and 8.

A rake may be turned into a gatherer, either by lifting up the rake-head bodily, and fixing it upon the rake-arm, which travels round in the same path as before; or else by causing the rake-arm to take a low path in front of the grain, and a second or higher cam path whilst passing over the platform. The disadvantage of the first method is that the gatherer has not the low path given in the second, and so is not able to cope so efficiently with a laid crop.

The rakes may be set as gatherers before starting to work, when the machine is at rest; but it is sometimes desirable to suspend the action of one or more of the rakes whilst at work. It is then necessary that the driver should be able, from his seat, and while the machine is in motion, to shunt the rake on to the higher path; and this is done by means of a switch, or movable portion of the cam.

The draught of a reaper is taken from the main frame, and a side-draught arrangement is sometimes used, the draught being taken through the inclined bar I, Fig. 25, Plate 8. The tipping of the fingers, by means of the handle K and link L, as shown in Fig. 24, Plate 7, is always provided for in side-delivery reapers, either in this or some other equivalent form. The usual width of cut is from 5 ft. to 5 ft. 6 in., and the average weight of the machine is from 10 to 11 cwt. for side-delivery, and from 5 to 6 cwt. for manual reapers.

In designing a Reaper, care should be taken to keep the line of cut in the same vertical plane as the centre line of the main axle, in order to follow the unevenness of the ground, and also to avoid

cutting into the soft soil when turning the corners. In some cases this line cannot be maintained, and then this latter fault is overcome by making the wheel M at the outer end of the cutter-bar to swivel, as shown in Fig. 15, Plate 4.

In concluding we may notice a class of machine which is used as a combined mower and side-delivery reaper. This is a two-wheeled machine, and has the cutter-bar B placed behind the main wheels W, so that the rakes R throw the sheaf clear of the wheels; the general plan is shown in Fig. 26, Plate 9. This combined machine is likely to come into use only where the crops are not very heavy and not much laid; but it is a useful machine where the crops on a farm consist chiefly of grass, and the expense of a separate self-raking reaper would otherwise have to be incurred for a small area of grain.

Automatic Sheaf-Binders.—These have been for many years past a fruitful subject of invention; but it may safely be said that at the present time there is not a binder that can cope successfully with a heavy English crop, unless it stands fairly upright. On the other hand due credit must be given to the Americans, who have produced machines capable of dealing with the short dry crops of their own country; and also to the English makers who have produced machines applicable to such crops as are grown in the colonies, and in the south of Europe.

The material used for binding the sheaves is either wire or string. A strong prejudice is shown by farmers against the use of wire, on account of its finding its way, in the hands of a careless labourer, into the thrashing machine, thence into the chaff, and occasionally between the millstones. But this difficulty can be overcome if a pair of pliers are used, which cut and hold the wire at the same time. The advantage of using wire, from a manufacturer's point of view, is that it presents far less difficulty to deal with, as a twist only is required in order to fasten the two ends together, whilst with string a knot is necessary, and the tension and cutting of the knot requires more attention.

The crop may either be cut and bound in sheaves in one operation, and upon the same machine, or else it may be cut by an ordinary side-delivery reaper, and then followed by a binder, which

picks up the loose sheaf or swathe from the ground, and binds it. As this latter form of machine is not in use in this country, and only to a very slight extent in America, the writer will confine his attention to the first class.

The usual design of a binder is shown in Fig. 29, Plate 10. In this case, a gathering reel L is substituted for the rakes of a reaper, and the cut crop falls upon a travelling platform A, from which the grain is elevated over the main travelling wheel by means of endless aprons BB, and falls on to a table C upon the other side. Under or above this table is placed the knotting or twisting mechanism. The wire or string is placed round the sheaf, when sufficient corn has been collected, by a radiating or rotating arm N, carrying a needle, as in Figs. 27–37, Plates 9 to 12; and when the knot or twist has been made, the string or wire is cut, and the sheaf is either kicked, or allowed to fall, off the binding platform on to the ground.

The elevating aprons B, Fig. 29, are generally made of canvas in pairs, and receive the grain from an endless canvas A, which travels over the platform; in other cases, instead of canvas aprons, endless bands, or chains provided with small teeth, are used.

The framework of these machines is usually built of timber, for the sake of combining lightness with rigidity; the shoe at the outer end of the cutter-bar is also of wood, with a separator of the same material. A better separation of the crop is made with this form of divider than with dividing irons, when a reel and not a rake is used, and when the cut crop has to be carried away from the outer side of the platform to the binding table.

The reel is driven by chain gearing from the main axle, and is capable of being raised and lowered, with respect to the cutter-bar, by suitable tilting gear, worked by a lever within reach of the driver. The fingers are also tipped, and the cutter-bar raised and lowered, as before. The beam in all machines of American manufacture is a wooden one, the knife serrated, and the sections or blades, as shown in Fig. 5, Plate 1*C*, of a more obtuse angle than in the ordinary English machines.

These machines are cumbersome, weighing about 15 cwt., and, as they measure about 12 ft. 6 in. in width, are incapable of passing straight through an ordinary English gateway. They must therefore

be drawn in sideways upon wheels provided for that purpose, or the cutter-bar must be hinged and capable of being turned up.

Another and more simple plan than that of elevating the cut grain over the main travelling wheel, is to keep it upon the level of the platform A, Fig. 30, Plate 10, on which it falls when first cut, to bind it on this level at C, and then to drop it upon the ground at G. In this form of machine the main wheel must be beyond or outside of the binding apparatus; the whole width of the machine is not increased thereby, but rather diminished. The weight of this machine is $12\frac{1}{4}$ cwt. and the width 12 feet. This form of machine has been in practical work in America, and has also been worked successfully in this country during the past harvest, in heavy and occasionally even tangled crops.

Wire-binding Mechanism.—In most cases the necessary twist is given by means of a small pinion, between the teeth of which the wire is brought, and the pinion then caused to revolve by putting it into gear with a rack or spur wheel. After having made three or four revolutions, the ends are sheared, and the bound sheaf set free, the loose end of the wire being still retained by means of a pair of jaws or nippers. The other end of the wire is brought into the pinion again, after having been passed round the next sheaf by the arm or needle. This needle-arm N, in one design, Figs. 33 and 34, Plate 11, carries the twisting pinion P itself; and, through the courtesy of the firm of Walter A. Wood, the writer is enabled to show one of their binder needles so constructed. In their machine, this needle-arm N makes a complete revolution, and, in passing under the binding table, the pinion P comes into gear with a rack R, which gives the necessary twist to the ends the wire.

Another plan is to give the needle-arm a radial oscillating movement, Fig. 35, Plate 11. This is done by suspending the needle-arm N above the binding table, on a revolving link C, and guiding the tail end of the needle-arm in the necessary path by means of a fixed slotted cam-link L; the needle-arm then simply gathers sufficient corn to make a sheaf, passes one end of the wire under it to the twisting device, taking itself the position shown by the full

lines; and, after the twist has been formed, rises up above the table, as shown dotted in two positions, returning nearly along its previous descending path, ready for another sheaf.

Again, instead of causing the needle-arm to oscillate or radiate as described above, the bracket which carries it is sometimes caused to travel inwards from the outer edge of the binding table to the shoots from the elevators, as shown in front elevation in Fig. 36, Plate 12; and then outwards again, after the binding and pressing arms have enclosed a sheaf between them for binding, as shown in back elevation in Fig. 37.

The function of the needle-arm is thus to gather sufficient of the loose corn to form a sheaf, and separate it, whilst being bound, from that which is still falling in a continuous stream behind it; to bring the end of the wire or string to the twisting or knotting device, and to compress the sheaf whilst being bound, in order to give the necessary degree of tightness to the band. This compression is sometimes put upon the sheaf by separate compressing arms, as shown at AA in Figs. 33, 36, and 37, Plates 11 and 12.

In Wood's machine, Fig. 33, the sheaf when bound is kicked off by the combined compressor arm and kicker A; whilst in the case of the McCormick and other machines the sheaf remains upon the binding table, and is pushed off by the succeeding sheaf.

In Figs. 27 and 28, Plate 9, is shown another successful plan for forming the twist, by means of two small pinions TT, working face to face. These have the same number of teeth, namely ten, but gear into two spur wheels FF, having respectively forty-eight and forty-nine teeth; which are caused to revolve simultaneously by the smaller spur wheel S, lying underneath them, coming into gear with the rack. Thus, as the pinions T revolve, the one gains upon the other, and after having made four revolutions, the teeth of one lie over the spaces in the other, and by this action shear the ends of the wire. In this machine two reels of wire are employed, the wire forming a continuous band from one to the other, and the jaws or nippers for holding one end of the wire are dispensed with. Instead of having one twist, two are made at the same time, one above and one below the double pinion T, as shown in Fig. 27.

In Fig. 30, Plate 10, is shown a still more simple form than any of those yet described. A revolving needle N, shown enlarged in Fig. 31, brings the wire round the sheaf to a small twisting-hook T, which takes hold of the two ends of the wire, and fastens them together in the usual way; a pair of shear-knives SS are then brought into operation by the crank U, as shown in Fig. 31, and the sheaf is kicked off gently on to the ground by a kicker K, Fig. 32, one end of the wire remaining looped on the hook T ready for the next sheaf.

String-binding Mechanism.—Fig. 38, Plate 13, is a sectional elevation of the binding table in one of Messrs. Walter A. Wood's string binders, showing the knotting device, &c.

Here the knotter is placed above the binding table T, whilst the needle-arm N rises up from below. The grain falls over the travelling wheel, after having been elevated in the usual manner, on to the binding table, and is brought over the string by a revolving packer P, against a compressor arm A. As soon as sufficient has been collected to form a sheaf, the pressure upon the arm A releases a spring (not shown), which in its turn causes the needle-arm N to rise up and pass round the sheaf, as shown dotted, the packer P in the meantime discontinuing to revolve.

The knot is formed as shown in Figs. 39 to 43, Plate 13. These figures show in inverted plan the two knotting hooks E F forming the knotter: the lower one F receiving its rotating movement by means of a spindle passing through the hollow spindle of the upper hook E, Fig. 38.

The needle-arm brings one end of the string over the knotter, the other end being already there, retained by the jaws or nippers J, as shown in Fig. 39; while the loop L (partly shown) contains the sheaf. The knotting hooks are then caused to rotate; but the upper hook E advances for a short distance before the lower one F commences to move, thus opening or separating the two hooks from each other.

After the hooks have made a quarter revolution, as shown in Fig. 40, the spur G on the heel of the lower hook F is brought over

the two ends of the string; and, in the next half revolution, the string slips under the hub of the lower hook, and comes into the position shown in Fig. 41.

When the hooks have reached this position, they cease to rotate forward, and commence to turn back in the opposite direction. In so doing, the upper hook E passes first over the two ends of the string, and closes into the recess upon the lower hook, thus grasping the ends of the string and holding them fast; then, as the hooks continue to rotate backwards, the spring-catch or hook S draws the loop over the end of the hook F, into the position shown in Fig. 42.

During the formation of this part of the loop, the jaws or nippers J, Fig. 39, release the end of the string and take hold of the other end, namely that passing through the binding needle N, at the same time cutting it. The two ends of the band which is round the sheaf are now loose; and the hooks E F continuing to revolve backwards, the knot is completed by means of the spring-catch S, as shown in Fig. 43, the weight of the sheaf drawing the knot tight.

The arm A now rises up out of the way, and the bound sheaf is kicked off the table by a kicker K on to the ground, the binding needle N at the same time receding under the table. The arm A then returns to its former position, and the packer P commences to form another sheaf.

This method ensures the sheaves being of a uniform size; and this size can be regulated in the first instance by the amount of tension put upon the spring actuated by the arm A for raising the needle-arm N.

In Figs. 44 to 46, Plate 13, is shown another and more simple method employed for forming the knot in a string binder. It consists of a hollow knotting-shaft A having a hook or jaw C at one end; inside this shaft is a sliding spindle B, which also has a hook or jaw D as shown. The spindle B has an independent longitudinal movement given to it, but rotates with the main shaft A. These movements are given by suitable gearing not shown in the diagram.

The knot is formed as follows. One end of the string is held in a pair of jaws or nippers, and then passed over the shaft A. The corn falls upon the string, and as soon as a sheaf is collected, the

other end of the string is brought round the sheaf and laid across the shaft A. The knotter shaft is then drawn back, as in Fig. 44, and makes a revolution; and in so doing it moves forwards at the same time, and brings the ends of the string between the open jaws C D, as in Fig. 45. The jaw D then closes upon the string and holds the ends fast; the string is cut, and the loop lifted over the hook C by a trigger E, as shown in Fig. 46; thus forming the knot, which is drawn tight by the weight of the sheaf. The shaft A being now pushed forwards again into its first position, and the jaws C D opening at the same time, the sheaf falls to the ground.

The difficulties to be contended with in automatic binders are numerous. The proper separation of the sheaf from the continuous flow of corn, and the getting rid of the sheaf when bound, require much careful consideration; and further, the tension and cutting of the binding material require great nicety of adjustment.

The binding mechanism, whether for wire or string, is generally carried upon a sliding shaft or upon ways, so that the sheaf may be bound near the middle of its length, whatever length the straw may be.

Although, owing to want of time, the writer has described only a few of the methods for making the twist or knot, he does not wish it to be imagined that other devices are void of merit or interest; but those described are, he believes, the plans chiefly used in this country and on the Continent, and he has therefore selected them as being the most suitable to the present occasion.

In conclusion he wishes to express his best thanks to the firm of Walter A. Wood for their kind assistance in lending models of their wire and string binding devices &c., and also to Mr. A. C. Bamlett for the use of those of his Mower and Manual Reaper.

Discussion.

Mr. SAMUELSON exhibited models of several of the machines described, and parts of the wire-binding and string-binding mechanisms; also specimens of the fingers in all the different stages of manufacture, as made by Messrs. Samuelson & Co.

The PRESIDENT was sure the members would wish to pass a hearty vote of thanks to Mr. Samuelson for his paper. It was most interesting and instructive, and was written in a very clear and concise manner. The diagrams might be taken as a sample, having been prepared by the author without any assistance being given by the draftsman of the Institution—an example which other members might advantageously follow.

Mr. J. McFARLANE GRAY thought the paper an admirable one. It contained so much that was new to most of the members, and so many beautiful mechanical devices were so clearly illustrated by the coloured wall diagrams, that he thought it might be worth while considering whether arrangements could not be made that such illustrations should be reproduced in colours in the transactions.

Mr. DANIEL ADAMSON said, as a Cheshire farmer, he was present only as a listener to the paper, with the view of perhaps subsequently becoming a buyer, rather than to criticise the subject dealt with. He thought with the President that they were all very much indebted to Mr. Samuelson for his exceedingly clear delineations of the machines, and his excellent description of them. He would only ask if the author could give the tractive power of the machines per foot wide, say for three classes of crops—poor crops, moderate crops, and heavy crops. Knowing the tractive power, farmers like himself would be better able to judge as to the horses that would be required to haul the machines. He might also ask for some further information as to what became of the wire on every

occasion that it was found during the thrashing of the corn, when a wire-binder had been used; and whether it was found to be injurious to the thrashing machine. Would the author recommend a string-binding machine in preference to wire? In the case of wire-binding, was it the system to shear the wire asunder in undoing the sheaf, or was it untwisted at the knot and taken away?

Mr. W. E. Rich, referring to Mr. Adamson's question as to the draught necessary to draw reaping machines through various kinds of crops, said he could not do better than refer him to the Journal of the Royal Agricultural Society. That Society on three occasions in recent years had made elaborate experiments upon the draught of reaping machines; and the results were given in Tables with great detail in the Society's Journals (1877, pp. 246–280; 1878, p. 103; 1879, pp. 106–8). Those Tables gave in the first place the leading dimensions of each machine, the width of cut, width between fingers, weight on each wheel, &c.; and then the speed, mean draught, draught per inch width of cut, and in some cases the ft.-lbs. of work per lb. of sheaf corn cut, in various crops, during the trials. This last statistic was really the most equitable measure of the economic performance of a machine. It might be read also as the distance through which the sheaf must be raised to represent the power expended in cutting and harvesting it. In the best ordinary reaping machines that had been brought before the Royal Agricultural Society the work expended per lb. of wheat sheaf was about 400 ft.-lbs.; in other words the sheaf required to be raised about 400 feet, to represent the work expended in cutting it. The self-binding machines required considerably more power, probably in consequence of the greater elaboration of their working parts. The self-binders tried in a heavy wheat crop at Liverpool required an average of 437 ft.-lbs. per lb. of sheaf corn cut and bound; while in a lighter wheat crop at Bristol 587 ft.-lbs. was required by them (see Journal 1878, p. 125; and 1879, p. 106). The mean draught per inch width of cut averaged from $3\frac{1}{4}$ to $4\frac{5}{8}$ lbs. with two-horse reaping machines at Leamington (see Journal 1877, Table I. facing p. 254); and from $7\frac{3}{4}$ to $8\frac{1}{2}$ lbs. in self-binding reapers cutting wheat at Liverpool.

Mr. M. Powis Bale said it was stated on p. 37 that a circular saw was used to cut a slot in the fingers of mowing machines. Could the author give some information with regard to the speed and gauge of the saw, and the shape of the tooth? He should also like to ask whether the machine was well adapted to cut such crops as rice, which were usually cut about a foot from the ground.

Mr. A. Paget wished to suggest that the reason of the short discussion which had followed this paper, and also that in Manchester on Spinning Machinery, was that these papers were really too good for most engineers to discuss on the spur of the moment. Following a paper at the ordinary rate at which it was read, and without any previous examination of both the paper and the drawings, it was really difficult to understand fully a paper of so abstruse a character. He was sure however they ought to thank Mr. Samuelson very much for his most valuable paper; and he ventured to draw attention to the great extent of unexplored territory, as indicated by the divisions mentioned in the paper. There was the preparation of the land, the sowing of the seed, the harvesting of the crops, and the preparation of the crops for consumption. He hoped on some future occasion Mr. Samuelson would give them an opportunity of listening to as excellent a paper on some other of these divisions; and he would venture to suggest that on that occasion the discussion might be adjourned, so as to give the members more time to digest the subject before discussing it.

Mr. Samuelson, in reply, said with reference to the wire in wire-binders, they sometimes did hear of small pieces being found amongst the chaff, and occasionally they were found inside the animals, but that was only under very exceptional circumstances. If wire were cut with a pair of pliers such as those exhibited, which would both cut and hold the wire at the same time, then, with a careful labourer, there ought never to be the chance of wire finding its way into the thrashing machine or amongst the chaff. In these pliers there was a shear knife on one side and a V groove on the other. When the man put the pliers into the sheaf and cut the wire, one end was

held in the pliers by the V groove, while the other end was loose; the man simply opened the pliers and took away the wire. Although in this way no wire had any business to pass into the thrashing machine, yet sometimes it did so, and for that reason farmers objected to the use of wire. On the other hand some farmers would not have string-binders, because they were too complicated: but on the whole the tendency was to adopt them, and most manufacturers were devoting their energies almost entirely to the perfection of string-binders. Several were already in the market, and he hoped that at the next Royal Society's show some more of these would be brought forwards. String, he believed, was decidedly the best, and would eventually take the place of wire, if the farmers would undertake to study the machine, and especially the mechanism required to make the knot. Unfortunately farmers did not like to give themselves more trouble than was necessary, and consequently string-binders would be liable to be badly used, and to fail where a wire-binder would not do so, on account of its simpler mechanism.

With regard to cutting rice, some machines would cut as high as 9 or 10 in. from the ground. If required to cut higher, it was only a question of raising the cutter-bar so much higher from the ground; and this could be done by making special axle-plates to carry the off-side and main-shoe wheels, so that it was quite possible to cut as high as 12 in. from the ground. In cutting rice, another thing had to be taken into consideration, namely the drains and irrigation channels. Large travelling wheels were wanted to carry the machines safely over these, otherwise they would come to a stand-still in them; but with sufficiently large travelling wheels, and also off-side wheel and main-shoe wheel, the machines could get over any moderate channel.

With regard to the saw used for the fingers, the gauge was No. 8 B. W. G., and the teeth were about $\frac{5}{8}$ in. pitch. The diameter of the saw was 22 in., and its speed about 800 to 900 revs. per minute. The fingers of course were put into the fire and made hot before sawing.

With reference to the division of the subject in the first page of the paper, it was not his, but was made by Mr. Bousfield, in his paper read at the Manchester meeting, Proc. 1880, p. 529. Mr. Bousfield had taken then the preparation of the land, or the first division, for

his subject, and he believed Mr. Bousfield intended to continue that subject in a second paper. He had himself taken the third division, and he hoped other gentlemen would take up the remainder.

ON THE VARIOUS MODES OF TRANSMITTING POWER TO A DISTANCE.

By M. ARTHUR ACHARD, of Geneva.

The Author proposes in this paper to furnish a summary of the practical results obtained in the Transmission of Power to a distance, a subject on which some articles of his have appeared in the Annales des Mines, between 1874 and 1879.

While the interest attaching to this subject is unquestionable, the Author is nevertheless very doubtful whether a successful result can be attained in one particular application, namely the establishment of large undertakings for distributing hydraulic power to a number of factories, either existing or contemplated, similar to the undertakings at Schaffhausen, Fribourg, and Bellegarde, which the Author has elsewhere described in detail.* At the first of these places, in spite of favourable circumstances, rapid extension of working, and good management, the profit has been very small on the capital outlay. The manufactories at the two other places, being much less favourably situated, have failed after a short and profitless existence. Their failure has shown very clearly that their founders laboured under a strange delusion, in supposing that cheap motive power was in itself sufficient to create industries in localities where their essential elements were wanting. The Author accordingly considers there is not much to be gained from this particular application of power transmission, and that it can only succeed financially under exceptionally favourable conditions.

He now proceeds to examine the various methods used, or proposed, for transmitting power to a distance.

* For a description of the Schaffhausen undertaking, see Mr. Morrison's paper, Proceedings, 1874, p. 56.

I. Transmission of Power by Wire Ropes.

Transmission by wire ropes is merely an extension of the simplest case of transmission by ordinary hemp ropes, and the same principles apply to both. These principles may be briefly stated as follows :—

Let A and B be the axes of two parallel shafts carrying two pulleys whose planes coincide. The driving power P acts on A, and the resistance Q on B. For simplicity let it be assumed that these two forces act tangentially at the circumference of the pulleys. The motion is communicated from A to B by means of the rope passing round the two pulleys; of this the part which is passing towards the driving pulley is called the driving span, and the part which is passing from the driving pulley is called the trailing span. Let T be the tension of the driving span, and t that of the trailing span. Neglecting friction &c. we should have $Q = P$; and the values of the tensions in the two spans are given by the equations $T - t = P$ and $\frac{T}{t} = k$; denoting by k the smallest practicable value of $e^{f\alpha}$ for the two pulleys, where e is the base of Napierian logarithms, f the coefficient of friction between the pulley and the rope, and α the ratio between the arc encircled by the rope and the radius of the pulley. Accordingly the values of T and t are given by the following equations :—

$$T = \frac{kP}{k-1}; \quad t = \frac{P}{k-1}.$$

If the ratio $\frac{T}{t}$ be greater than k, the rope will slip on the driving pulley. The values of T and t, as above calculated, when k has its exact value, are only just sufficient to prevent slipping, which would occur on any accidental diminution of friction. For safety therefore it is necessary to assign to k a somewhat lower value than its real one: which practically amounts to increasing the tensions T and t a little beyond what is requisite in theory. The tension common to the whole rope when at rest is somewhere intermediate between the tensions T and t of its two spans while running; and by adjusting the rope while at rest to this intermediate tension, its two spans

assume of their own accord the required tensions T and t, as soon as it begins to run.

The sectional area w to be given to the rope, so that it may possess the requisite strength, is regulated by the driving tension T, and must be such that the quotient $\frac{T}{w}$ shall not exceed the working strain which the material of the rope is suited to bear in practice. It is evident that, in transmitting a given amount of power, the driving tension, and consequently the section of the rope, may be diminished by increasing the speed; for if N denotes the power transmitted, and v the speed of the rope, then $Pv = N$, and $T = \frac{kP}{k-1} = \frac{k}{k-1} \frac{N}{v}$. In practice the rope elongates under the continuous pull, and requires shortening from time to time to keep the tension up to the proper amount.

We will now take into account the useless resistances, hitherto neglected for the sake of simplicity. The useful resistance Q is now necessarily less than the driving power P, and the ratio $\frac{Q}{P}$ represents the efficiency of the transmission. The useless resistances are two in number. The first is the rigidity or stiffness of the rope, due to its imperfect flexibility. This effect however is insignificant in the case of rope transmission, on account of the large size of the pulleys employed. The other useless resistance is the friction of the two shafts A and B in their bearings, of which one of the factors is the resultant F of all the external forces acting on each shaft. It appears from the principles enunciated above that the employment of rope transmission renders this friction considerable. In fact, under average conditions of adhesion, the value to be allowed for $k = e^{f\alpha}$ is not more than 2; and since in the limit $\frac{T}{t} = k$, and $T = \frac{kP}{k-1}$, we have as the least possible values $T = 2\ P$, and $t = P$. These tensions are parallel to each other; and as the driving power P may also act in the same direction, the total pressure F on the shaft may be $T + t + P = 4\ P$, as a minimum, where the conditions are the most unfavourable; while under the most favourable conditions the pressure on the bearings will be given by $F = T + t - P = 2\ P$, as a minimum.

Hence the average pressure may be taken as at least 3 P. It is evident therefore that rope transmission renders the shaft friction much greater than does transmission by toothed wheels. But the effect of this friction is much reduced by the large diameter of the pulleys in comparison with that of their shafts, in consequence of which the pressure on the shaft bearings has to be multiplied by a number not exceeding at most $0 \cdot 003$, in order to obtain the resulting friction on the shaft.

The introduction of iron wire ropes for transmitting power to a distance has arisen from the necessity of replacing leather or india-rubber by some material less expensive, less affected by atmospheric influences, less extensible, and especially possessing a much higher tensile strength. The large amount of the power which must exist to make special machinery advantageous for transmitting it to a distance does not constitute one of the reasons for the change of material, inasmuch as belts of leather and india-rubber are capable of transmitting very considerable power. In reality they owe this capability to a special property which they possess ; and which releases them completely from the theoretical laws to which attention has just been directed in the case of ropes. If the belt is wide, a partial vacuum is produced between the belt and the rim of the pulley, by the aid of an adequate velocity, which causes the atmospheric pressure to press the belt close against the pulley. An adhesion is thereby produced which is totally independent of friction, and enables the tensions to be considerably reduced. Accordingly the tension T of the driving span, instead of attaining the value 2 P, need only equal P. A great reduction of the friction on the bearings is thereby effected, and there is a greater power of transmission with the same section. Thus, whilst formerly in large factories the belts served only to transmit the power from the main driving shafts to the different machines, they are beginning to be employed to drive the main shafts themselves from the prime mover. The Americans were the first to adopt this course. This extended use of belts is regulated by certain practical rules which it may perhaps be useful to point out. It is advisable to make the belts travel at a high speed, 4000, 5000, and even 6000 ft.

per minute, which leads to the adoption of large diameters for the pulleys. As flexibility is essential, it is preferable not to double the leather, but to rest satisfied with the greatest single thickness, amounting to $\frac{5}{16}$ or $\frac{3}{8}$ inch, and to resort to large widths. As the adhesion does not depend on the friction, the roughness of the surfaces in contact is more injurious than useful; and accordingly, contrary to the old practice, the hair or grain side of the leather, being the smoothest, is turned to the pulley. Since the even motion of the pulleys is a very important condition, it is advisable to employ, as far as possible, light and perfectly-balanced pulleys, and supports with a wide base and movable bearings. It is for this reason that American pulleys are sold by the piece and not by weight. The widths which the Americans give to belts put up on this principle are such that the circumferential strain, $P = \frac{N}{v}$, is 50 lbs. to 67 lbs. per inch of width, which represents a strain of 156 lbs. to 185 lbs. per square inch of section. There was a leather belt at the Philadelphia Exhibition of 1876 which had a width of 5 ft.; but generally they barely exceed $3\frac{1}{4}$ ft. or 4 ft.; while for greater widths several belts are employed, placed side by side.

The invention of iron wire ropes for power transmission is due to M. Ch. Ferdinand Hirn, of Colmar in Alsace. These ropes are composed of a certain number of strands, each having a core of hemp, which are rolled round a central core, also of hemp. They are wound on in the opposite direction to that of the wires in each strand. The pulleys are of large diameter, which tends to the preservation of the ropes, helps to render the effect of the stiffness insignificant, and diminishes the effect of the friction of the bearings. If the distance is considerable, the transmissions are divided into several relays, with a separate rope for each. The relays are separated by stations. Each station is provided with a horizontal shaft upon which a double-grooved pulley is fixed, which is the driven pulley as regards the relay terminating there, and the driving pulley in reference to the succeeding relay. The stations are usually arranged on masonry pillars, more or less raised according to the configuration of the ground, for it is necessary that the rope should be in no danger of

touching the ground. Sometimes the power has to be partially distributed in its course: under these circumstances the shafts at the stations are made use of for the purpose. Frequently also it is necessary to place intermediate pulleys along a relay, which differ from the end pulleys of the relay in serving merely to support the rope. Occasionally a relay has been made 650 feet long, but usually 420 to 500 feet is the limit.

The weights of the most ordinary sizes of pulleys employed, including their shafts, are on an average as follows:—

DIAMETER.		WEIGHT.			
		Single-groove Pulley.		Double-groove Pulley.	
metres.	feet. in.	kilogrammes.	lbs.	kilogrammes.	lbs.
5·50	18 0	2775	6232	3750	8267
4·50	14 9	2350	5180	3170	6988
3·75	12 4	1100	2425	1850	4078
2·13	7 0	362	798	528	1164

The pulleys have grooves of the shape of a V, rounded off at the bottom, and having there a swallow-tailed notch in which the lagging is fixed. Experience proves that the best lagging is made of pieces of leather, cut from the hide in the form of the notch, and placed in it end upwards. When these are filled in all round, the pulley is once more placed in the lathe, so as to turn down the bottom of the groove to the section required. This lagging lasts on an average three years. It wears out most rapidly on the intermediate pulleys; it has been observed that the rotation of these pulleys is more rapid than the motion of the rope, which occasions slipping.

The iron wires of which the rope is made have to bear two distinct molecular strains. The first, designated by s, is the tension resulting from the maximum tension T necessary to transmit the motion, and its value, in lbs. per sq. in. is accordingly $s = \frac{T}{\frac{\pi}{4} d^2 i}$, d being the diameter of the wires, and i their number. The second strain results from the flexure produced by the winding upon the pulley, and may

be expressed with sufficient accuracy by $z = E \frac{d}{2R}$; R being the radius of the pulley, and E the modulus of elasticity of iron, say 20,000 kg. per sq. mm., or 28,445,000 lbs. per sq. in. It is clearly necessary that the sum of these strains, $s + z$, should not exceed a certain limit, which is fixed at 18 kilogrammes per sq. mm. (25,600 lbs., or say 11 tons, per sq. in.) In most of the ropes with which the Author is acquainted the values allowed are approximately $s = 10$ kg. (14,220 lbs. per sq. in.), and $z = 8$ kg. (11,380 lbs. per sq. in.) The speed of the ropes may without any inconvenience attain, and even exceed, 20 metres per second (4000 feet per minute, or 45 miles per hour). To preserve the ropes from oxidation and improve their adhesion, they are coated with a heated mixture of grease and resin. A special machine, invented by M. D. H. Ziegler, engineer at Winterthur, enables the ropes to be subjected to a preliminary squeezing to increase their length; by this means the subsequent elongation from wear and tear is diminished, and the number of shortenings which become necessary is reduced.

It is difficult to lay down any general rule as to the duration of the ropes, for this depends upon the conditions under which they work. In practice it must not be assumed that a rope in constant use will last more than a year. In fact Professor Amsler-Laffon recently wrote to the Author on the subject of the ropes at Schaffhausen: "A rope lasts about one year, some a little more, some a little less. But it must be understood that we do not wait till our ropes break, but replace them as soon as we can no longer depend on their strength. They might therefore last rather longer, if we chose to run the risk of interruption in our work." The same duration has been found at Zurich in the case of a rope transmission, established by the municipality to supply a manufacturer whom they had deprived of his water power. The short life of the ropes is certainly a defect in this mode of transmitting power. According to M. Ziegler, who has considerable experience on this subject, horizontal oscillations are very injurious to the duration of the ropes, and they appear to last longer on pulleys with wide grooves than with narrow grooves.

The curve in which the rope hangs is a catenary; and it is upon the form of the particular catenary in which it hangs, whether more or less deep, as well as upon its lineal weight, that the tension to which it is subjected depends. By fixing the weight of the rope and its length, the form which its two spans assume in common, when at rest, is determined, and consequently their common tension; which latter must be such as to produce in running the two unequal tensions, T and t, necessary for the transmission of the power.

Moreover, the tension in either span is not the same throughout its whole length; it is a minimum at the lowest point of the curve, and goes on increasing towards the two extremities. The calculation of the tension at the lowest point is very complicated if based upon the true form of the catenary; but by substituting a parabola for the catenary, which is allowable in almost all cases, the calculation becomes very simple. If the two pulleys are on the same level, the lowest point is midway between them, and the tension at this point is $S_0 = \frac{pl^2}{8h}$, p being the lineal weight of the rope, l its horizontal projection, which is approximately equal to the distance between the centres of the pulleys, and h the deflection in the middle. The catenary possesses the remarkable mechanical property that the difference between the tensions at any two points is equal to the weight of a length of rope corresponding to the difference in level between the two points. The tensions therefore at the two ends will be $S_1 = S_0 + ph = \frac{pl^2}{8h} + ph$. By substituting for S_1 in the above equation the required values of T and t, and solving it with relation to h, the deflections h_1 and h_2 of the driving and trailing spans will be obtained. The deflection h_0, common to the two spans at rest, is given by the equation $h_0 = \sqrt{\frac{1}{2} h_1^2 + \frac{1}{2} h_2^2}$. If, as before, w represents the sectional area of the iron portion of the rope, s the unit strain which the maximum tension T produces on it, we have $w\,s = T = \frac{pl^2}{8h_1} + ph_1$. Taking the sectional area w of the rope in square inches, and its weight p in lbs. per foot run, the ratio $\frac{w}{p}$ differs little from a mean value of 0·24 (104 in French measures);

and as previously stated the safe limit of working tension usually assigned for iron-wire ropes is $s = 14{,}220$ lbs. per sq. in. (French measures $s = 10$ kg. per sq. mm.) Hence $\frac{w}{p}s = 0 \cdot 24 \times 14{,}220 = 3410$; and we have the approximate equation $\frac{l^2}{8h_1} + h_1 = 3410$ (French measures 1040), which is useful as giving a relation between the length l and deflection h_1, for the driving span of a rope. In the case of leather, $\frac{w}{p} = 2 \cdot 53$ approximately (French measures 1100); and as it is impossible to give s a higher value than about 355 lbs. per sq. in. (0·25 kg.), the relation obtained would be $\frac{l^2}{8h_1} + h_1 = 900$ (French measures 275), which with equal deflections would give much shorter spans. If the working tension s were reduced to the American limit of 185 lbs. per sq. in. (0·13 kg.) for leather belts, the above figure 900 would be reduced to 470 (French measures 143), which would further shorten the span nearly one-half.

It is therefore owing to the great strength which iron wire ropes possess in proportion to their weight that they admit of long spans, with a smaller number of supports, and consequently smaller loss of power by friction. They may therefore be expected to yield a high efficiency. As a matter of fact the experiments of M. Ziegler on the transmission of power at Oberursel give for the mean efficiency of a single relay $\frac{Q}{P} = 96 \cdot 2$ per cent. The efficiency of transmission by relays, including m intermediate stations, is approximately obtained by raising the efficiency of a single relay to the power of $\frac{m+2}{2}$.

It often happens that the two pulleys of a single relay are at different levels, in which case neither span of the rope has the same tension at its two extremities: the tension at the upper end of each exceeds that at the lower by the quantity $p\,H$, H being the difference in level between the two extremities, or, which is approximately the same, between the centres of the two pulleys. It is evidently the tension of the driving span at its lower end which must be regulated so as to obtain the proper driving tension T for the

transmission: so that there is a certain excess of tension at the upper pulley.

When power has to be transmitted to the top of a very steep incline, the establishment of a relay station exactly at the top of the incline is generally avoided; intermediate pulleys are put there in preference, one for each span, the relay itself being prolonged for a certain distance on the level. This is the course which has been adopted for the transmission of power from the two turbines at Bellegarde, where a height of about 115 feet has to be surmounted. The Author would refer to his published article for the description of the transmission by ropes at Oberursel, Schaffhausen, Fribourg, and Bellegarde, as it would be impossible to abridge the account sufficiently for the present paper.

II.—Transmission by Compressed Air.

Hitherto the method of transmission by compressed air has only been used, so far as the Author is aware, for boring the headings of mines, and the long tunnels through the Alps. In these cases, as is well known, the work to be done consists in a rapid boring of holes for the purpose of blasting the rock with powder or dynamite. As this kind of work requires a high pressure of air, and almost entirely precludes the employment of expansion, the utilisation of the motive force is necessarily defective; but in consequence of the peculiar convenience which compressed air offers for the work, and particularly the improved ventilation which it affords, the advantage of its employment is undoubted, and leaves in the background the question of efficiency. If however this method were resorted to for driving through rock soft enough to be excavated directly by the mining tool, it is possible that expansion might be used in the machine working the tool.

In the case of the transmission of power for general industrial purposes, the question of efficiency is usually of great importance. The ultimate efficiency of transmission is the product of three partial efficiencies: (1) that of the air-compressing machine; (2) that of the pipes by which the compressed air is conveyed; and (3) that of the machine which the compressed air works. The efficiency of the

prime mover, and that of the tools worked by the compressed-air machine, should not be brought into this estimate.

The air-compressing machines, generally called compressors, are piston pumps,* having self-acting inlet and outlet mitre valves, controlled by springs and worked by the air pressure itself.

The essential condition to be fulfilled by an air-compressor is that the temperature of the air during compression should as far as possible be kept constant: the reason, as is well known, being as follows. Let P be the power expended in compressing a given initial volume of atmospheric air into a given final volume, whilst fulfilling this condition. If the air were compressed in a cylinder impermeable to heat, the heat resulting from the compression would remain in it, and would raise its temperature and pressure, thus involving the expenditure of a power P_1, greater than P, for its compression. But after the compression had been effected, the temperature of the compressed air would rapidly fall to the surrounding temperature, and would only represent a store of power P_2, less than P; thus the powers $P_1 - P$ and $P - P_2$, making together $P_1 - P_2$, would be lost. Even if the metal barrel of the compressing pump is not absolutely impermeable to heat, it is impossible to avoid not merely important losses of power, but also an amount of heating that is very injurious both to the working and to the durability of the machine. It is only by the help of water that the rise of temperature can successfully be kept down within moderate limits.

The Seraing or water-piston compressor was first tried with this object. The great defect of this apparatus is the loss of power resulting from the alternating movement imparted to a large body of water. This loss is approximately proportional to the volume displaced by the piston, raised to the power $\frac{5}{3}$, and to its speed raised to the power $\frac{4}{3}$. To reduce this loss it would be necessary to

* The impact compressor, combining the functions of a hydraulic motor and a compressor, which was employed at the commencement of the driving of the Mont Cenis tunnel, need not be included in the list. In spite of its apparent simplicity, it was found to be costly, cumbersome, inefficacious, and easily deranged, and was very soon abandoned. It would unquestionably require further improvements to render it applicable even in very special cases.

divide the required production of compressed air amongst a great number of compressors, and to make them work slowly, by giving them large dimensions. This renders the first cost of erection, and the space required, comparatively large. The speed of the compressors working on this system at Mont Cenis was limited to 8 or 10 revolutions per minute; and that of the smaller compressors, which have been used for headings in mines, has been generally limited to 15 or 18 revolutions.

It was next attempted to employ the water for cooling in a manner which, whilst efficacious, should not entail the above loss of power, and should admit of a higher speed of working. The object was accomplished by two methods, which can be used separately or together. One consists in making the water circulate through a casing surrounding the pump-barrel, and through cavities formed inside the piston and piston-rod. The other method, which is still more efficacious, consists in injecting a very fine spray into the pump barrel, whereby the water is brought into direct contact with the air to be cooled. Both these methods, suggested by M. Colladon, have been applied, under his instructions, to the St. Gothard compressors, and have furnished excellent results. These machines have perfectly answered their purpose, and have worked at a speed of 60 to 80 revolutions per minute, producing only a very limited rise in temperature.

The efficiency of the St. Gothard compressors has been approximately from 78 to 80 per cent. The Author regrets that he is unable to give more precise figures; but M. Colladon, the consulting engineer of the tunnel works, informed him, only a short time ago, that no experiments had been made as to this efficiency; and more particularly that the effective force of the hydraulic motors which work them had never been measured. M. Colladon had however the kindness to furnish the results of a trial made with one of his compressors at the works of Messrs. Sautter and Lemonnier of Paris, the makers of the machine. These experiments would show an efficiency of 86 per cent. Nevertheless it is not possible to place implicit reliance on this result, because the effective power of the motor was not determined by experiment. But allowing that the

figure of 22 H.P., assumed for this power (the result in calculating the work with compressed air being 19 H.P.), may be somewhat incorrect, it is unlikely that the error can be so large that its correction would reduce the efficiency below 80 per cent. Messrs. Sautter and Lemonnier, who construct a number of compressors, on being consulted by the Author, have written to say that they had always confined themselves to estimating the power stored in the compressed air, and had never measured the power expended in compressing it.

Compressed air in passing along the pipe, assumed to be horizontal, which conveys it from the place of production to the place where it is to be used, experiences by friction a diminution of pressure, which represents a reduction in the mechanical power stored up, and consequently a loss of efficiency. The loss of pressure in question can only be calculated conveniently on the hypothesis that it is very small, and the general formula employed for the purpose is—

$$\frac{p_1 - p}{\Delta} = \frac{4\,L}{D} f(u),$$

where D is the diameter of the pipe, assumed to be uniform, L the length of the pipe, p_1 the pressure at the entrance, p the pressure at the farther end, u the velocity at which the compressed air travels, Δ its specific weight, and $f(u)$ the friction per unit of length. In proportion as the air loses pressure its speed increases, whilst its specific weight diminishes; but the variations in pressure are assumed to be so small that u and Δ may be considered constant.

As regards the quantity $f(u)$, or the friction per unit of length, the natural law which regulates it is not known, and it can only be expressed by some empirical formula, which, whilst according sufficiently nearly with the facts, is suited for calculation. For this purpose the binomial formula $au + bu^2$, or the simple formula $b_1\,u^2$, is generally adopted; a, b, and b_1 being coefficients deduced from experiment. The values however which are to be given to these coefficients are not constant, for they vary with the diameter of the pipe; and in particular, contrary to formerly received ideas, they vary according to its internal surface. The uncertainty in this respect is so

great that it is not worth while, with a view to accuracy, to relinquish the great convenience which the simple formula $b_1 u^2$ offers. It would be better from this point of view to endeavour, as has been suggested, to render this formula more exact by the substitution of a fractional power in the place of the square, rather than to go through the long calculations necessitated by the use of the binomial $au + bu^2$. Accordingly, making use of the formula $b_1 u^2$, the above equation becomes,

$$\frac{p_1 - p}{\Delta} = \frac{4\,L}{D} b_1 u^2 ;$$

or, introducing the discharge per second, Q, which is the usual figure supplied, and which is connected with the velocity by the relation $Q = \frac{\pi D^2 u}{4}$ we have

$$\frac{p_1 - p}{\Delta} = \frac{64}{\pi^2} \frac{b_1}{D^5} L\,Q^2.$$

Generally the pressure p_1 at the entrance is known, and the pressure p has to be found; it is then from p_1 that the values of Q and Δ are calculated. In experiments where p_1 and p are measured directly, in order to arrive at the value of the coefficient b_1, Q and Δ would be calculated for the mean pressure $\frac{1}{2}(p_1 + p)$.

The values given to the coefficient b_1 vary considerably, because, as stated above, it varies with the diameter, and also with the nature of the material of the pipe. It is generally admitted that it is independent of the pressure, and it is probable that within certain limits of pressure this hypothesis is in accordance with the truth.

D'Aubuisson gives for this case, in his "Traité d'Hydraulique," a rather complicated formula, containing a constant deduced from experiment, whose value, according to a calculation made by the Author, corresponds approximately to $b_1 = 0{\cdot}0003$. This constant was determined by taking the mean of experiments made with tin tubes of 0·0235 m. ($\frac{15}{16}$ inch), 0·05 m. (2 inches), and 0·10 m. (4 inches) diameter; and it was erroneously assumed that it was correct for all diameters and all materials.

M. Arson, engineer to the Paris Gas Company, published in 1867, in the "Mémoires de la Société des Ingénieurs Civils de

France," the results of some experiments on the loss of pressure in gas when passing through pipes. He employed cast-iron pipes of the ordinary kind. He has represented the results of his experiments by the binomial formula $au + bu^2$, and gives values for the coefficients a and b, which diminish with an increase in diameter, but would indicate greater losses of pressure than D'Aubuisson's formula.

M. Devillez, in his "Rapport sur les travaux de percement du tunnel sous les Alpes," states that the losses of pressure observed in the air-main at the Mont Cenis tunnel confirm the correctness of D'Aubuisson's formula; but his reasoning applies to too complex an air-main to be absolutely convincing.

Quite recently M. E. Stockalper, engineer-in-chief at the northern end of the St. Gothard tunnel, has made some experiments on the air-main of this tunnel, the results of which he has kindly furnished to the Author. These lead to values for the coefficient b_1 appreciably less than that which is contained implicitly in D'Aubuisson's formula. As he experimented on a rising pipe, it is necessary to introduce into the formula the difference of level h between the two ends; it then becomes—

$$\frac{p_1 - p}{\Delta} = \frac{64\, b_1}{\pi^2\, D^5} L\, Q^2 + h.$$

The following are the details of these experiments:—

First series of Experiments.—Air-main consisting of cast-iron pipes, joined by means of flanges, bolts, and india-rubber rings. D = 0·20 m. (8 in.); L = 4600 m. (15,100 ft.); h = 26·77 m. (87 ft. 10 in.).

1*st Experiment.*—Q = 0·1860 cub. m. (6·57 cub. ft.), at a pressure of $\frac{1}{2}(p_1 + p)$, and a temperature of 22° Centigrade (72° Fahrenheit); p_1 = 5·60 atm., p = 5·24 atm. Hence $p_1 - p$ = 0·36 atm. = 0·36 × 10334 kilogrammes per sq. metre (2116 lbs. per sq. ft.); whence we obtain b_1 = 0·0001697.

D'Aubuisson's formula would have given $p_1 - p$ = 0·626 atm.; and M. Arson's would have given $p_1 - p$ = 0·92 atm.

2*nd Experiment.*—Q = 0·1566 cub. m. (5·53 cub. ft.), at a pressure of $\frac{1}{2}(p_1 + p)$, and a temperature of 22° Cent. (72° Fahr.); p_1 = 4·35 atm., p = 4·13 atm. Hence $p_1 - p$ = 0·22 atm. = 0·22 × 10334

kg. per sq. m. (2116 lbs. per sq. ft.); whence we obtain $b_1 = 0 \cdot 0001816$.

D'Aubuisson's formula would have given $p_1 - p = 0 \cdot 347$ atm.; and M. Arson's would have given $p_1 - p = 0 \cdot 53$ atm.

3rd Experiment.—Q = $0 \cdot 1495$ cub. m. ($5 \cdot 28$ cub. ft.), at a pressure of $\frac{1}{2}(p_1 + p)$ and a temperature of 22° Cent. (72° Fahr.); $p_1 = 3 \cdot 84$ atm., $p = 3 \cdot 65$ atm. Hence $p_1 - p = 0 \cdot 19$ atm. $= 0 \cdot 19 \times 10334$ kg. per sq. m. (2116 lbs. per sq. ft.); whence we obtain $b_1 = 0 \cdot 0001966$.

D'Aubuisson's formula would have given $p_1 - p = 0 \cdot 284$ atm., and M. Arson's would have given $p_1 - p = 0 \cdot 43$ atm.

Second series of Experiments.—Air-main composed of wrought-iron pipes, with joints as in the first experiments. D = $0 \cdot 15$ m. (6 inches), L = 522 m. (1712 feet), $h = 3 \cdot 04$ m. (10 feet).

1st Experiment.—Q = $0 \cdot 2005$ cub. m. ($7 \cdot 08$ cub. ft.), at a pressure of $\frac{1}{2}(p_1 + p)$, and a temperature of $26° \cdot 5$ Cent. (80° Fahr.); $p_1 = 5 \cdot 24$ atm., $p = 5 \cdot 00$ atm. Hence $p_1 - p = 0 \cdot 24$ atm. $= 0 \cdot 24 \times 10334$ kg. per sq. m. (2116 lbs. per sq. ft.); whence we obtain $b_1 = 0 \cdot 0002275$.

2nd Experiment.—Q = $0 \cdot 1586$ cub. m. ($5 \cdot 6$ cub. ft.), at a pressure of $\frac{1}{2}(p_1 + p)$, and a temperature of $26° \cdot 5$ Cent. (80° Fahr.); $p_1 = 3 \cdot 650$ atm., $p = 3 \cdot 545$ atm. Hence $p_1 - p = 0 \cdot 105$ atm. $= 0 \cdot 105 \times 10334$ kg. per sq. m. (2116 lbs. per sq. ft.); whence we obtain $b_1 = 0 \cdot 0002255$.

It is clear that these experiments give very small values for the coefficient. The divergence from the results which D'Aubuisson's formula would give is due to the fact that his formula was determined with very small pipes. It is probable that the coefficients corresponding to diameters of $0 \cdot 15$ m. (6 in.) and $0 \cdot 20$ m. (8 in.) for a substance as smooth as tin would be still smaller respectively than the figures obtained above. The divergence from the results obtained by M. Arson's formula does not arise from a difference in size of pipes, as this is here taken into account. The Author considers that it may be attributed to the fact that the pipes for the St. Gothard tunnel were cast with much greater care than ordinary pipes, which rendered their surface smoother; and also to the fact that flanged joints produce

much less irregularity in the internal surface than the ordinary spigot and faucet joints. Lastly, the difference in the methods of observation, and the errors appertaining to these, must be taken into account. M. Stockalper, who experimented on high pressures, used metallic gauges, which are instruments on whose sensibility and correctness complete reliance cannot be placed; and the standard gauge with which they were compared was also one of the same kind. The Author is not of opinion that the divergence is owing to the fact that M. Stockalper made his observations on an air-main in which the pressure was much higher than in gas pipes. Indeed it may be assumed that gases and liquids act in the same manner; and, as will be explained later on, there is reason to believe that with the latter a rise of pressure increases the losses of pressure instead of diminishing them.

All the pipes for supplying compressed air in tunnels and in headings of mines are left uncovered, and have flanged joints; which are advantages not merely as regards prevention of leakage, but also for facility of laying and of inspection. If a compressed-air pipe had to be buried in the ground, the flanged joint would lose a part of its advantages; but nevertheless the Author considers that it would still be preferable to the ordinary joint.

It only remains to refer to the motors supplied by the compressed air. This subject is still in its infancy from a practical point of view. In proportion as the air becomes hot by compression, so it cools by expansion, if the vessel containing it is impermeable to heat. Under these conditions it gives out in expanding a power appreciably less than if it retained its original temperature; besides which the fall of temperature may impede the working of the machine, by freezing the vapour of water contained in the air. If it is desired to utilise to the utmost the force stored up in the compressed air, it is necessary to endeavour to supply heat to the air during expansion, so as to keep its temperature constant. It would be possible to attain this object by the same means which prevent heating in compression, namely, by the circulation and injection of water. It would perhaps be necessary to employ a rather larger quantity of water for injection,

as the water, instead of acting by virtue both of its heat of vaporisation and of its specific heat, can in this case act only by virtue of the latter.

These methods might be employed without difficulty for air machines of some size. It would be more difficult to apply them to small household machines, in which simplicity is an essential element; and we must rest satisfied with imperfect methods, such as proximity to a stove, or the immersion of the cylinder in a tank of water. Consequently loss of power by cooling and by incomplete expansion cannot be avoided. The only way to diminish the relative amount of this loss is to employ compressed air at a pressure not exceeding 3 or 4 atmospheres.

The only real practical advance made in this matter is in Mékarski's compressed-air engine for tramways. In this engine the air is made to pass through a small boiler, containing water at a temperature of about 120° Cent. (248° Fahr.), before entering the cylinder of the engine. It must be observed that in order to reduce the size of the reservoirs, which are carried on the locomotive, the air inside them must be very highly compressed; and that in going from the reservoir into the cylinder it passes through a reducing valve, or expander, which keeps the pressure of admission at a definite figure; so that the locomotive can continue working so long as the supply of air contained in the reservoir has not come down to this limiting pressure. The air does not pass the expander until after it has gone through the boiler already mentioned. Therefore, if the temperature which it assumes in the boiler is 100° Cent. (212° Fahr.), and if the limiting pressure is 5 atm., the gas which enters the cylinder will be a mixture of air and water-vapour at 100° Cent.; and of its total pressure the vapour of water will contribute 1 atm. and the air 4 atm. Thus this contrivance, by a small expenditure of fuel, enables the air to act expansively without injurious cooling, and even reduces the consumption of compressed air to an extent which compensates for part of the loss of power, arising from the preliminary expansion which the air experiences before its admission into the cylinder.

It is clear that this same contrivance, or, what amounts to the same thing, a direct injection of steam, at a sufficient pressure, for the purpose of maintaining the expanding air at a constant temperature, might be tried in a stationary engine worked by compressed air with some chance of success. Whatever method is adopted, it would be advantageous that the losses of pressure, in the pipes connecting the compressors with the motors, should be reduced as much as possible, for in this case that loss would represent a loss of efficiency. If, on the other hand, owing to defective means of reheating, it is necessary to remain satisfied with a small amount of expansion, the loss of pressure in the pipe is unimportant, and has only the effect of transferring the limited expansion to a point a little lower on the scale of pressures.

If W is the net available power from the shaft of the engine which works the compressor, v_1 the volume of air supplied by the compressor at the pressure p_1 and at the temperature of the surrounding air, and p_0 the atmospheric pressure; then the efficiency of the compressor, assuming the air to expand according to Boyle's law, is given by the well-known formula—

$$\frac{p_1 v_1 \log \frac{p_1}{p_0}}{W}.$$

Let p_2 be the value to which the pressure is reduced by the loss of pressure at the end of the pipe, and v_2 the volume which the air occupies at this pressure and at the same temperature: then the force stored up in the air at the end of its course through the pipe is $p_2 v_2 \log \frac{p_2}{p_0}$. Consequently the efficiency of the pipe is

$$\frac{p_2 v_2 \log \frac{p_2}{p_0}}{p_1 v_1 \log \frac{p_1}{p_0}};$$

a fraction which may be reduced to the simple form $\frac{\log \frac{p_2}{p_0}}{\log \frac{p_1}{p_0}}$ if there is no leakage during the passage of the air, because in that case $p_2 v_2 = p_1 v_1$.

Lastly, if W_1 is the net available power from the shaft of the compressed-air motor, the efficiency of this engine will be—

$$\frac{W_1}{p_2 \, v_2 \log \frac{p}{p_0}};$$

and the product of these three partial efficiencies is equal to $\frac{W_1}{W}$, the general efficiency of the transmission.

III.—Transmission by Pressure-Water.

As transmission of power by compressed air has been specially applied to the driving of tunnels, so transmission by pressure-water has been specially resorted to for lifting heavy loads, or for work of a similar nature, such as the operations connected with the manufacture of Bessemer steel, or of cast-iron pipes. The Author does not propose to treat of transmissions established for this special purpose, and depending on the use of accumulators at high pressure, as he has no fresh matter to impart on this subject, and as he believes that the remarkable invention of Sir William Armstrong was described, for the first time, in the Proceedings of the Institution of Mechanical Engineers. His object is to refer to transmissions applicable to general purposes.

The transmission of power by water may occur in another form. The motive force to be transmitted may be employed for working pumps which raise the water, not to a fictitious height in an accumulator, but to a real height in a reservoir, with a channel from this reservoir to distribute the water so raised amongst several motors arranged for utilising the pressure. The Author is not aware that works have been carried out for this purpose. In many towns however a part of the water from the public mains serves to supply small motors: consequently if the water, instead of being brought by a natural fall, has been previously lifted artificially, it might be said that a transmission of power is here grafted on to the ordinary distribution of water.

Unless a positive or negative force of gravity is introduced into the problem, independently of the force to be transmitted, it must be

assumed that the motors supplied with the pressure-water are at the same level as the forcing pumps; or more correctly that the exhaust from those motors is at the same level as the surface of the water from which the pumps draw their supply. In this case the general efficiency of transmission is the product of three partial efficiencies, which correspond exactly to those mentioned with regard to compressed air.

The height of lift, contained in the numerator of the fraction which expresses the efficiency of the pumps, is not to be taken as the difference in level between the surface of the water in the reservoir and the surface of the water whence the pumps draw their supply; but as this difference in level, *plus* the loss of pressure in the suction pipe, which is usually very short, and *plus* the loss in the channel up to the reservoir, which may be very long. A similar loss of initial pressure affects the efficiency of the discharge channel from the reservoir. Such a reservoir, if of sufficient capacity, may become an important store of power; whilst the compressed-air reservoir can only be so to a very limited extent.

Omitting the subject of the pumps, and passing on at once to the water mains, the Author may first point out that the distinction between the ascending and the descending mains of the system is of no importance, for two reasons: firstly, that nothing prevents the motors being supplied direct from the first alone; and secondly, that the one is not always distinct from the other. In fact the reservoir may be connected by a single branch pipe with the system which extends from the pumps to the motors: it may even be placed at the extreme end of this system beyond the motors, provided always that the supply-pipe is taken into it at the bottom.

The same formula may be adopted for the loss of initial pressure in water pipes as for compressed-air pipes, viz.

$$\frac{p_1 - p}{\delta} = \frac{64}{\pi^2} \frac{b_1}{D^5} L Q^2 \pm h;$$

h being the difference of level between the two ends of the portion of pipe of length L, and the sign $+$ or $-$ being used according as the pipe rises or falls. The specific weight δ is constant, and the quotients $\frac{p_1}{\delta}$ and $\frac{p}{\delta}$ represent the heights z_1 and z to which the water

could rise above the pipe, in vertical tubes branching from it, at the beginning and end of the length L.

The values assigned to the coefficient b_1 in France are those determined by D'Arcy. For new cast-iron pipes he gives—

$$b_1 = 0 \cdot 0002535 + \frac{1}{D} 0 \cdot 00000647;$$

and recommends that this value should be doubled, to allow for the rust and incrustation which more or less form inside the pipes during use. The determination of this coefficient was made from experiments in which the pressure did not exceed 4 atmospheres; within these limits the value of the coefficient, as is generally admitted, is independent of the pressure. The experiments made by M. Barret, on the pressure pipe of the accumulator at the Marseilles docks, seem to indicate that the loss of pressure would be greater for high pressures, everything else being equal. This pipe, having a diameter of 0·127 m. (5 in.), was subjected to an initial pressure of 52 atmospheres. The Author gives below the results obtained for a straight length of 320 m. (1050 ft.); and has placed beside them the results which D'Arcy's formula would give.

Velocity of Flow. Per second.		Loss of Head, in metres or feet respectively per 100 metres or feet run of pipes.		
		Actual Loss observed.	Calculated Loss.	
			Old pipes.	New pipes.
Metres.	Feet.	Met. or Ft.	Met. or Ft.	Met. or Ft.
0·25	0·82	1·5	0·12	0·06
0·50	1·64	2·5	0·48	0·24
0·75	2·46	3·7	1·08	0·54
1·00	3·28	5·5	1·92	0·96
1·25	4·10	6·1	3·00	1·50
1·50	4·92	7·3	4·32	2·16
1·75	5·74	8·0	5·88	2·94
2·00	6·56	10·2	7·68	3·84
2·25	7·38	11·7	9·72	4·86
2·50	8·20	14·0	12·00	6·00

Moreover, these observed results would appear to indicate a different law from that which is expressed by the formula $b_1 u^2$, as is easy to see by representing them graphically. It would be very

desirable that fresh experiments should be made on water pipes under high pressure, and of various diameters.

Of machines worked by water pressure, the Author proposes to refer only to two, which appear to him in every respect the most practical and advantageous.

One is the piston machine of M. Albert Schmid, engineer at Zurich. The cylinder is oscillating, and the distribution is effected without an eccentric, by the relative motion of two cylindrical surfaces fitted one against the other, and having the axis of oscillation for a common axis. The convex surface, which is movable and forms part of the cylinder, serves as a port-face, and has two ports in it communicating with the two ends of the cylinder. The concave surface, which is fixed and plays the part of a slide-valve, contains three openings, the two outer ones serving to admit the pressure-water, and the middle one to discharge the water after it has exerted its pressure. The piston has no packing. It has grooves turned in its circumference, which produce a sort of water packing, maintained by adhesion. A small air-chamber is connected with the inlet pipe, and serves to deaden the shocks. This engine is often made with two cylinders, having their cranks at right angles.

The other engine, which is much less used, is a turbine on Girard's system, with a horizontal axis and partial admission, exactly resembling in miniature those employed in raising water at the waterworks of St. Maur, near Paris. The water is introduced by means of a distributor, which is fitted inside the turbine casing, and occupies a certain portion of its circumference. This turbine has a lower efficiency than Schmid's machine, and is less suitable for high pressures; but it possesses this advantage over it, that by regulating the amount of opening of the distributor, and consequently the quantity of water admitted, the power can be altered without altering the velocity of rotation. As it admits of high speeds, it could be usefully employed direct, without the interposition of spur-wheels or belts, for driving magneto-electric machines employed for the production of light, for electrotyping, &c.

In compressed-air machines the losses of pressure due to incomplete expansion, cooling, and waste spaces, play an important part. In water-pressure machines loss does not occur from these causes, on account of the incompressibility of the liquid; but the frictions of the parts are the principal causes of loss of power. It would be advisable to ascertain whether, as regards this point, high or low pressures are the most advantageous. Theoretical considerations would lead the Author to imagine that for a piston machine low pressures are preferable.

In conclusion, the following Table gives the efficiencies, as measured in 1871 by Professor Fliegner, of a Girard turbine, constructed by Messrs. Escher Wyss and Co. of Zurich, and of a Schmid machine:—

Escher Wyss and Co.'s Girard Turbine.				Schmid Motor.			
Effective Head of Water.		Revolutions per minute.	Efficiency.	Effective Head of Water.		Revolutions per minute.	Efficiency.
Metres.	Feet.	Revs.	Per cent.	Metres.	Feet.	Revs.	Per cent.
..	..	..	..	8·3	27·2	226	37·4
..	..	..	..	11·4	37·4	182	67·4
..	..	..	..	14·5	47·6	255	53·4
..	..	..	..	17·9	58·7	157	86·2
20·7	67·9	628	68·5	20·7	67·9	166	89·6
20·7	67·9	847	47·4	20·7	67·9	225	74·6
..	..	..	..	24·1	79·0	238	76·7
24·1	79·0	645	68·5	24·1	79·0	389	64·0
27·6	90·5	612	65·7	27·6	90·5	207	83·9
27·6	90·5	756	68·0	..	..	..	..
31·0	101·7	935	56·9	..	..	..	..
31·0	101·7	1130	35·1	..	..	..	..

It will be observed that these experiments relate to low pressures; it would be desirable to extend them to higher pressures.

IV.—Transmission by Electricity.

However high the efficiency of an electric motor may be, in relation to the chemical work of the electric battery which feeds it, force generated by an electric battery is too expensive, on account of

the nature of the materials consumed, for a machine of this kind ever to be employed for industrial purposes. If however the electric current, instead of being developed by chemical work in a battery, is produced by ordinary mechanical power in a magneto-electric or dynamo-electric machine, the case is different; and the double transformation, first of the mechanical power into an electric current, and then of that current into mechanical power, furnishes a means for effecting the conveyance of the power to a distance.

It is this last method of transmission which remains to be discussed. The Author however feels obliged to restrict himself in this matter to a mere summary; and indeed it is English physicists and engineers who have taken the technology of electricity out of the region of empiricism, and have placed it on a scientific and rational basis. Moreover they are also taking the lead in the progress which is being effected in this branch of knowledge, and are best qualified to determine its true bearings.

When an electric current, with an intensity i, is produced, either by chemical or mechanical work, in a circuit having a total resistance R, a quantity of heat is developed in the circuit; and this heat is the exact equivalent of the power expended, so long as the current is not made use of for doing any external work. The expression for this quantity of heat, per unit of time, is Ai^2R; A being the thermal equivalent of the unit of power corresponding to the units of current and resistance, in which i and R are respectively expressed.

The product i^2R is a certain quantity of power, which the Author proposes to call *power transformed into electricity*. When mechanical power is employed for producing a current by means of a magneto-electric or dynamo-electric machine,—or, to use a better expression, by means of a *mechanical generator of electricity*,—it is necessary in reality to expend a greater quantity of power than i^2R, in order to make up for losses which result either from ordinary friction or from certain electro-magnetic reactions which occur. The ratio of the quantity i^2R to the power W actually expended per unit of time is called the efficiency of the generator. Designating it by K, we have

$$W = \frac{i^2R}{K}.$$

It is very important to ascertain the value of this efficiency, considering that it necessarily enters as a factor into the evaluation of all the effects to be produced by means of the generator in question.

The following Table * gives the results of certain experiments made early in 1879, with a Gramme machine, by an able physicist, M. Hagenbach, Professor at the University at Basle, and kindly furnished by him to the Author :—

No. of Experiment.	1	2	3	4
Revolutions per minute	893	900·5	919·5	935
Total Resistance in Siemens units	6·06	4·94	3·82	2·55
Total Resistance in absolute units	$5·787 \times 10^9$	$4·718 \times 10^9$	$3·648 \times 10^9$	$2·435 \times 10^9$
Intensity in chemical units	6·28	8·09	10·99	17·67
Intensity in absolute units	1·005	1·295	1·759	2·828
Work Done i^2R in absolute units	$584·9 \times 10^7$	$791·3 \times 10^7$	$1129·2 \times 10^7$	$1948·6 \times 10^7$
Work Done i^2R in kilogrammetres	59·62	80·66	115·1	198·6
Power Expended in kilogrammetres	83·25	86·25	141·0	301·5
Efficiency ......per cent.	71·6	93·5	81·6	65·9

M. Hagenbach's dynamometric measurements were made with a brake. After each experiment on the electric machine, he applied the brake to the engine which he employed, taking care to make it run at precisely the same speed, with the same pressure of steam, and with the same expansion, as during the experiment. It would certainly be better to measure the force expended during, and not after, the experiment, by means of a registering dynamometer. Moreover M. Hagenbach writes that his measurements with the brake were very much prejudiced by external circumstances: doubtless this is the reason of the divergences among the results obtained.

About the same time Dr. Hopkinson communicated to this Institution the results of some very careful experiments made on a Siemens machine. He measured the force expended by means of a

* See Mr. Shoolbred's conversion of these results into English nomenclature, p. 88 *infra*.

registering dynamometer, and obtained very high coefficients of efficiency, amounting to nearly 90 per cent. M. Hagenbach also obtained from one machine a result only $6\frac{1}{2}$ per cent. less than unity.

Mechanical generators of electricity are certainly capable of being improved in several respects, especially as regards their adaptation to certain definite classes of work. But there remains hardly any margin for further progress as regards efficiency.

Power transformed into electricity in a generator may be expressed by $i\omega MC$; ω being the angular velocity of rotation, M the magnetism of one of the intervening poles, either inducing or induced, and C a constant specially belonging to each apparatus, and independent of the units adopted. This constant could not be determined except by an integration practically impossible; and the product M C must be considered indivisible. Even in a magneto-electric machine (with permanent inducing magnets), and much more in a dynamo-electric machine (inducing by means of electro-magnets excited by the very current produced), the product M C is a function of the intensity. From the identity of the expressions i^2R and $i\omega MC$ we obtain the relation $MC = \frac{iR}{\omega}$, which indicates the course to be pursued to determine experimentally the law connecting the variations of M C with those of i. Some experiments made in 1876 by M. Hagenbach on a Gramme dynamo-electric machine appear to indicate that the magnetism M C does not increase indefinitely with the intensity, but that there is some maximum value for this quantity.

If, instead of working a generator by an external motive force, a current is passed through its circuit in a certain given direction, the movable part of the machine will begin to turn in the opposite direction to that in which it would have been necessary to turn it in order to obtain from it a current in the given direction. In virtue of this motion, the electro-magnetic forces which are generated may be used to overcome a resisting force. The machine will then work as a motor or receiver.

Let i be the intensity of the external current which works the motor, when the motor is kept at rest. If it is now allowed to move,

its motion produces, in virtue of the laws of induction, a current in the circuit, of intensity i_1, in the opposite direction to the external current: the effective intensity of the current traversing the circuit is thus reduced to $i - i_1$. The intensity of the counter current is given, like that of the generating current, by the equation $i_1^2 R = i_1 \omega_1 M_1 C_1$, or $i_1 R = \omega_1 M_1 C_1$; the suffix $_1$ denoting the quantities relating to the motor. Here $M_1 C_1$ is a function of $i - i_1$, not of i.

As in a generator the power transformed into electricity has a value $i \omega M C$, so in a motor the power developed by electricity is $(i - i_1) \omega_1 M_1 C_1$. On account however of the losses which occur, the effective power W_1, that is the power available from the shaft of the motor, will have a smaller value; and in order to arrive at it a coefficient of efficiency K_1 must be added. We shall then have $W_1 = K_1 (i - i_1) \omega_1 M_1 C_1$. The Author has no knowledge of any experiments having been made for obtaining this efficiency K_1.

Next let us suppose that the current feeding the motor is furnished by a generator, so that actual transmission by electricity is taking place. The circuit, whose resistance is R, comprises then the coils, both fixed and movable, of the generator and motor, and the conductors which connect them. The intensity of the current which traverses the circuit had the value i when the motor was at rest; by the working of the motor it is reduced to $i - i_1$. The power applied to the generator is itself reduced to $W = \frac{(i - i_1) \omega M C}{K}$. The prime mover is relieved by the action of the counter current, precisely as the consumption of zinc in the battery would be reduced by the same cause, if the battery were the source of the current.

The efficiency of the transmission is $\frac{W_1}{W}$. Calculation shows that it is expressed by the following equations:—

$$\frac{W_1}{W} = K K_1 \frac{\omega_1 M_1 C_1}{\omega M C}, \text{ or } = K K_1 \frac{\omega_1 M_1 C_1}{\omega_1 M_1 C_1 + (i - i_1) R};$$

expressions in which it must be remembered $M C$ and $M_1 C_1$ are really functions of $(i - i_1)$.

This efficiency is then the product of three distinct factors, each evidently less than unity, namely the efficiency belonging to the generator, the efficiency belonging to the motor, and a third factor

depending on the rate of rotation of the motor and the resistance of the circuit. The influence which these elements exert on the value of the third factor cannot be estimated, unless the law is first known according to which the magnetisms M C and M_1 C_1 vary with the intensity of the current.

Casting a retrospective glance at the four methods of transmission of power which have been examined, it would appear that transmission by ropes forms a class by itself, whilst the three other methods combine into a natural group, because they possess a character in common of the greatest importance. It may be said that all three involve a temporary transformation of the mechanical power to be utilised into potential energy. Also in each of these methods the efficiency of transmission is the product of three corresponding factors or partial efficiencies:—namely, 1st, the efficiency of the instrument which converts the actual energy of the prime mover into potential energy; 2nd, the efficiency of the instrument which reconverts this potential energy into actual energy, that is into motion, and delivers it up in this shape for the final motors which perform useful work; 3rd, the efficiency of the intermediate agency which serves for the conveyance of potential energy from the first instrument to the second. This third factor has just been given for transmission by electricity. It is to a certain extent the correlative of the efficiency of the pipe, in the case of compressed air, or of pressure water.

It is as useful in the case of electric transmission, as of any other method, to be able, in designing a system, to estimate beforehand what results it will be capable of furnishing; and for this purpose it is necessary to calculate exactly the factors which compose the efficiency. In order to obtain this desirable knowledge, the Author considers that the three following points should form the aim of experimentalists:—

1st. The determination of the efficiency K of the principal kinds of magneto-electric, or dynamo-electric, machines working as generators.

2nd. The determination of the efficiency K_1 of the same machines working as motors.

3rd. The determination of the law according to which the magnetism of the cores of these machines varies with the intensity of the current.

The Author is of opinion that experiments made with these objects in view would be more useful than those conducted for determining the general efficiency of transmission; for the latter give results only available under precisely similar conditions. However it is clear that these have their value, and must not be neglected.

There are moreover many other questions requiring to be elucidated by experiment, especially as regards the nature of the conducting wires; but it is needless to dwell further upon this subject, which has been ably treated by many English men of science, for instance Dr. Siemens and Professor Ayrton. Nevertheless for further information the Author would refer to the able articles published in Paris by M. Mascart, in the "Journal de Physique," in 1877 and 1878.

The Author would gladly have concluded this paper with a comparison of the efficiencies of the four systems which have been examined, or, what amounts to the same thing, with a comparison of the losses of power which they occasion. Unfortunately such a comparison has never been made experimentally, because hitherto the opportunity of doing it in a demonstrative manner has been wanting; for the transmission of power to a distance belongs rather to the future than to the present time.

Transmission by electricity is still in its infancy; it has only been applied on a small scale, and experimentally. Of the three other systems, transmission by means of ropes is the only one that has been employed for general industrial purposes; whilst compressed air and water under pressure have been applied only to special purposes, and their use has been due much more to their special suitability for these purposes than to any considerations relative to loss of power. Thus the useful effect of the compressed air used in driving the tunnels through the Alps, assuming its determination to be possible, was undoubtedly very low; nevertheless, in the present state of our

appliances, this is the only process by which such operations can be accomplished.

The Author believes that transmission by ropes furnishes the highest proportion of useful effect; but that, as regards a wide distribution of the transmitted power, the other two methods, by air and water, might merit the preference.

Discussion.

The Secretary said he had received a letter from M. Achard expressing his regret that it was quite impossible for him to be present on that occasion, owing to a recent severe family loss.

Mr. J. N. Shoolbred observed that on p. 82 the author had given a Table of the results of M. Hagenbach's experiments, in a form that differed somewhat from that in which experiments of a similar character were tabulated in Dr. Hopkinson's papers (Proc. 1879, p. 249, and 1880, p. 268), and also as carried out by Mr. Gray of Silvertown (Proc. 1880, p. 276) on a Gramme machine of the same size as that referred to by M. Achard. He had thought it might be interesting if the experiments in the paper were tabulated in a form similar to that previously adopted, so that the data might be readily compared with those of Dr. Hopkinson and Mr. Gray: and he had done this in the Table on the next page.

Hagenbach's Experiments with Gramme Machine of "A" Size.

(See M. Achard's Table, p. 82 ante.)

Number of Experiment.	Total Resistance.	Current.			Work Done.			Power Expended.			Efficiency per cent.	Revolutions of Armature per Minute.
		Intensity.		Quantity.								
	Ohms.	Milligrammes of Water decomposed per sec.	Volts.	Webers.	Erg-tens.	Horse Power.	Kilogrammetres.	Erg-tens.	Horse Power.	Kilogrammetres.		
1	5·79	0·94	58·19	10·05	0·59	0·79	59·62	0·82	1·10	83·25	71·6	893
2	4·72	1·21	61·12	12·95	0·79	1·07	80·66	0·85	1·14	86·25	93·5	900·5
3	3·65	1·65	64·20	17·59	1·13	1·52	115·06	1·38	1·86	141·00	81·6	919·5
4	2·44	2·65	79·00	28·28	1·95	2·62	198·69	2·96	3·97	301·50	65·9	935

These experiments presented some rather peculiar results, and certain of the figures might be doubtful. In M. Hagenbach's original communication to M. Achard (which by M. Achard's kindness he had been allowed to inspect), a note was appended by M. Hagenbach himself to the experiment No. 4 in the accompanying Table, saying that the figures were somewhat uncertain; and he himself could not help thinking that in these experiments there had not been the same scrupulous attention to details, as had been given by Dr. Hopkinson and Mr. Gray. Still they were extremely valuable, and they bore out in a great measure the results of Mr. Gray's experiments upon a similar machine.

It should be borne in mind that M. Hagenbach's experiments, as well as those of Dr. Hopkinson and Mr. Gray, simply bore upon the question of the efficiency of magneto-electric machines, not upon the transmission of power. With regard to the question of transmission of power, some experiments, carried out under the direction of Dr. Siemens, and mentioned in a paper by Messrs. Higgs and Brittle (Proc. Inst. C.E., vol. lii., p. 53), showed, as Dr. Siemens had repeatedly stated, that there was practically a loss of about 50 per cent. in efficiency between the power imparted in the original motor, and that taken out from the second machine. This loss was caused by a counter current generated by the second machine, and subtractive from the efficiency of the first one. He had recently had the opportunity of making some experiments himself in reference to transmitted power. Though not complete, they were sufficient to enable him to suggest whether it might not be possible, by a certain arrangement between the proportions of the machines themselves and the speed at which they were driven, to reduce somewhat that percentage of loss. It was a very important question, whether a large loss like that could not be reduced in practice. Even with that loss there were certain applications in the industrial arts in which transmitted motion might be useful. There were in the first place large natural sources of power, which at present were useless, but which might be made use of in this way. The power cost nothing at the original site, and if it could be transmitted at a comparatively economical rate for use, it would prove exceedingly

valuable. For instance, a letter from Sir William Armstrong had appeared in *The Engineer* (21 Jan. 1881, page 49), with reference to some Swan electric lights which he had put up at his house at Rothbury. The power for those lights was taken from a brook at a distance of about three-quarters of a mile, and occasionally during the day the power transmitted was made use of for working a saw-bench, &c. In the next place, in the case of large works, the central source of power might be made use of in out-of-the-way parts, where it would be difficult and perhaps expensive to locate a separate engine. Again, in cases where running power existed, such as over-head travelling cranes, the moving parts and the connections might be considerably simplified and more economically constructed, where electricity was supplied. Electric motors were found to be more compact and economical than either steam or hydraulic motors.

With regard to locomotion caused by power transmitted by electricity, Dr. Siemens (Proc. Society of Telegraph Engineers, 1880, p. 301), when speaking of the electric railway at Berlin, had referred to the peculiar effect at the ascending or descending inclines. Now when the driven machine was either under-weighted or over-weighted, the effect was very similar to that at a descending or ascending incline, although the motor was stationary. He believed that this form of transmission by electricity might, under certain circumstances, receive very considerable extension. M. Achard had clearly pointed out the experiments that were required in order to give more information on this subject; and to these should be added the study of the best arrangement of machines, by which the present very large loss might be materially reduced.

Questions were so often asked as to any examples existing of the transmission of power by electricity, that it might be interesting to describe briefly what at present were probably the two most important examples of such transmission. One was the electric railway, first shown at the Exhibition at Berlin in 1879, by Dr. Werner Siemens, and afterwards at those in 1880 at Düsseldorf and Brussels. The machines for the Siemens railway were simply two equal machines, of their "medium" size. One was stationary and the other was driven by it, and was mounted on wheels. The stationary

machine transmitted the current in the first instance along a central rail laid on the railway, and from thence to the travelling machine. The motion of this machine was communicated to a pair of wheels which acted as driving wheels, and the return current took place through the ordinary rails. The arrangement was found, he believed, to develop in the motor about 4 or 5 HP., and the power given off in the travelling machine was estimated at 2 HP., or a little over. As to the power of the engine which worked the motor, he had no information. There were three or four cars drawn at Berlin, and he understood that the speed was from 15 to 20 miles an hour.

The other example was at M. Menier's chocolate works at Noisiel, which were visited by the members in 1878 on the occasion of the Paris meeting of the Institution. Since then M. Menier had been making use of the turbines, which gave him power from the river Marne for his works, to drive a pair of Gramme machines of a peculiar construction, and had applied the reproduction of the power for the purposes of ploughing. He had made use of two of Fowler's ploughs, at a distance in some cases of nearly three miles; placing a similar machine to the generators on each of two carriages, which took the place of the steam engines for working the plough. M. Gramme himself had constructed a machine especially for the purpose. It was practically a quadruple machine; there were four pairs of poles and four brushes. The arrangement was very compact, and he understood that as much as 16 or 18 HP. was given off by the initial machine. M. Henri Menier had had charge of the experiments on transmission of power by that machine at Noisiel, and probably they would shortly have the benefit of them. In the United Kingdom there were, he believed, but two minor examples: one at Messrs. Poynter's chemical works, Greenock, where a turbine was used to drive the first machine; and the second at Sir William Armstrong's private house, to which he had previously made reference. That was likewise driven by a turbine, taking water from a brook. In both cases the machines were by Siemens.

Mr. ALEXANDER SIEMENS thought that the author of the paper and Mr. Shoolbred attached far too much value to the question of

efficiency, both in the electric transmissions and in compressed-air transmission. It would be practicable in this way to use the great forces of nature, such as water-falls: to establish a sort of central station, and to distribute the power from thence to small motors at different points, either by hydraulic power, or by compressed air, or by electricity. In such cases the distribution of power would be useful, even with a loss of 50 per cent. or more, because at the central station the power could be obtained so cheaply. The transmission of power by electricity had a great advantage over the other two methods mentioned, because the leading wires were so much more manageable than either water pipes or air pipes. Sir William Armstrong had employed a Siemens medium sized machine in his works, and at his house he had been employing a small sized machine for several years and for several purposes; both these worked well. Dr. Siemens had also lately introduced, at his house at Tunbridge Wells, a small Tangye engine, working two electric-light machines, which were utilised at night for horticultural purposes, and in the daytime for cutting hay or turnips by transmitting their current to a dynamo-machine at the farm. There was also another dynamo-machine for pumping water to the house. Such applications were perfectly feasible, and they ought to be better known. It would be a great thing to establish in populous districts a central station, where an economical steam engine could be put up, from whence to distribute the power. He had no doubt that very soon this would be put into practice.

With regard to the experiments suggested by M. Achard (p. 85) to determine "the efficiency K of the principal kinds of generators," that work had already been done partly by M. Hagenbach and partly by Dr. Hopkinson. As to "the determination of the efficiency K_1 of the same machines working as motors," that had also been done by different experimentalists. The author was of opinion "that experiments made with these objects in view would be more useful than those conducted for determining the general efficiency of transmission; for the latter give results only available under precisely similar conditions." But those "precisely similar conditions" were easily obtained, because in the case of electric

transmission the leading wire between the machines could be given the same resistance, whether the distance was a mile or three-quarters. If the proper speed for the two machines was once determined, the same results could always be obtained by inserting the same amount of resistance between them. He thought therefore that the application of the transmission of power by electricity was at the present time hampered more by prejudice than by a want of knowledge on the part of its promoters.

Mr. J. FERNIE, having lived a short time in Geneva, might be permitted to say that it was a great misfortune the writer of the paper was not present, because he might have given them some information as to the practical application of water-power at Geneva for the purposes described. It was a very extraordinary thing that with the immense resources running to waste at Bellegarde, and with the machinery erected to take advantage of them, people would not go and settle down there. It had been suggested to him that the reason lay in the fact that there were no amusements for the workpeople at Bellegarde, and so nothing to induce them to settle there. Turbines had been erected, and everything made ready for a large population and for great manufactures to be established, but the people were slow in going there, and the money seemed to be wasted. In some large towns in Switzerland however, great advantage was being taken of water power, such as Englishmen had no idea of. Those who saw how conveniently and economically small machines were worked in that way would be surprised that something of the kind had not been done in England. In Geneva a company was formed which took advantage of the great fall of water in the Rhone. They had the water at high pressure, and let it out on hire; and all the little manufactories, such as watch manufactories, in Geneva, were supplied with power from that source. It was uncommonly cheap, and very regular, and there was no trouble about steam engines, boilers, &c. The man who came to cut wood for the house used in old times to bring a saw and trestles with him; but now he brought only a little hydraulic machine, which he connected to a pipe in the street, and sawed the wood in that way.

The resources in the way of water-power in Switzerland were immense, if they could only be used. During the time he resided in Geneva another company was formed to take the water of the Rhone as it left the Lake of Geneva, and carry it to a series of turbines, and so utilise the fall from the point where the river left the lake, to where it joined the Arve, a distance of three-quarters of a mile with a fall of 25 or 30 feet. Considering the enormous volume of the Rhone, it was easy to see what an immense power might be thus obtained; but the Genevese people were in great fear that the beauty of their city would be destroyed; they therefore protested against the scheme, and it came to an end.

He wished to ask whether steel had not been employed for the wire ropes, which were common all over Switzerland, as the author mentioned iron only; and it would be interesting to know the difference in the wear and tear between iron and steel. In connection with the transmission of power by means of wire ropes, he might mention that the Institution of Civil Engineers possessed an excellent set of photographs illustrating all the work of that kind which had been done in Switzerland: so that those who had not had the opportunity of examining that mode of conveying power might here see it well illustrated.

Mr. W. Schönheyder said the author had alluded (page 60) to the great advantage which leather belts possessed if they were made very wide—say three or four or five feet—because a partial vacuum was said to be formed under them, so that the adhesion was much greater than would be expected according to theory. He should like to know how the author had ascertained that: whether it had been tried, or whether it was only an assumption. It appeared to him more likely that the air would have a difficulty in getting away from between the pulley and belt on the in-going side. The wider the belt, the more difficult it appeared to him to be for the air to get out sideways: so that the air might rather be expected to accumulate, than to get away altogether in the way stated by the author. There was one point which the author had omitted to mention—the centrifugal force of the belt at very high velocities. He could not now say whether, with

the velocities mentioned of 4000 to 6000 feet per minute, the centrifugal force was enough to lessen the adhesion materially; but with very high velocities the belt tended to leave the pulley, and so made the adhesion less. At page 62 the author, speaking of wire-rope transmission, stated that the intermediate pulleys ran faster than the rope. That meant that slipping took place; and he supposed it was partly on account of that slipping (which ought not to take place) that wire ropes wore out so fast. It seemed monstrous to think that wire ropes should only be in use twelve months, or at most two years. He should like to know whether that was due to too high a working strain being allowed. The author mentioned 11 tons per sq. in., but did not say why he had adopted that figure. It appeared to him that if the ropes only lasted twelve months something must be wrong: either they were too tight, or too high a tension was allowed per square inch of section. Possibly heavier ropes would last much longer. The expense of renewing them every twelve months must be very serious.

At page 67, speaking of the transmission of power by the Seraing air-compressor, the author stated, "The great defect of this apparatus is the loss of power resulting from the alternating movement imparted to a large body of water." That seemed to him an error. Power was not lost by imparting reciprocating motion to water. Great force was required to start it or stop it, which however might be of advantage if driving by steam worked expansively; for it helped to take off the excessive pressure of steam at the beginning of the stroke, and gave a higher pressure at the end of the stroke, so that it acted as a kind of fly-wheel. Of course that class of air-compressors could not be worked as fast as one of the simple piston compressors. If it were, the water got into a state of agitation, and did not drive away all air through the ports; but he thought it was an error to say that power was lost by reciprocating water.

At page 78 a Table was given with regard to the friction in pipes at very high pressures. That was a new subject, which had not yet been investigated to anything like the proper extent. If this Table could be relied upon, it appeared that the friction due to high pressures was something like three or five times as great as might

be expected. From calculations he had recently made, when consulted about some heavy presses for pressing cotton by other means than hydraulic pressure, he was inclined to believe that was not so. He had indeed been told by a gentleman who had worked with hydraulic presses very largely in India, that the loss of pressure in hydraulic pipes was enormous. He could not believe the statement in the Table, p. 78, that the friction increased so much at a pressure of only 52 atmospheres, say 800 lbs. per sq. in.; but if so, how much must the friction have increased in the case to which he referred, where the pressure was perhaps two or three tons per square inch? He thought it would be well if some experiments could be made upon friction in hydraulic pipes, so that the question might be solved.

A friend had called his attention to the absence of any mention in the paper of another mode of transmitting power, namely by steam. It was used in this country,* but not for transmission to any distance. He understood however that it had been used to a large extent in Hartford, Connecticut, where steam had been carried as far as a mile with good results. He was sorry that he could not give the particulars.†

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* At Kippax Colliery, near Leeds, steam was conveyed 1030 feet from a boiler at surface to work an elevator in the pit. (See Proceedings Inst. M. E. 1861, p. 220.)

† On this head the following information has been supplied to the Secretary by Mr. H. Olrick :—"In the United States great interest is taken in the subject of the transmission of heat and power to the inhabitants of cities, by means of steam and highly heated water carried through pipes in the streets, and supplied to the houses and buildings in much the same way as water and gas are ordinarily supplied. Mr. Holley, the inventor of the high-pressure pumping system, was the first to make the experiment with steam in his native town of Lockport, New York, and he has laid down plant in several cities, supplying steam for heating purposes and for machines of small power. The most successful steam system however was put down at Hartford, Connecticut, by Mr. Burdett Loomis. This system occupies a mile and a half of piping, and supplies sufficient steam to heat 6,000,000 cubic feet of room space, or to supply about 150 HP. nominal. He informs me that with 70 lbs. boiler pressure, the pressure is reduced only 2 lbs. at a mile from the boilers; which at all events shows that his system of covering the pipes is very successful. This

Mr. J. G. MAIR said it was stated, p. 60, that the vacuum between the belt and the pulley was produced "by the aid of an adequate velocity." He should be obliged if the author would state precisely what was meant by that term, since at whatever speed the belt ran he could not see how a vacuum could exist. In reference to Mr. Schönheyder's remarks about belting, the calculations in the paper as to the running ropes were based on their being stationary. The centrifugal force, which had such an important influence when they were running, was not taken into account. The author had stated

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is done simply by means of creosoted logs, bored out so as to allow a 2 in. air-space to be maintained all round the wrought-iron pipes carrying the steam. These logs are driven one within the other at the ends, so that a perfectly tight joint is made and no air allowed to circulate in them; and it appears that this mode of covering is superior to any asbestos, hair, or felt covering which has been used up to the present time. At distances of about 100 feet are placed expansion joints, contained in man-holes which are also kept air-tight, but which can be opened for examining or tightening up the joints. All the condensed water is taken back to the boilers through a return pipe, laid alongside the steam pipe and covered in a similar manner, the water being trapped into this pipe from each building. This is a very important improvement, since it saves not only the heat of the return water but also the water itself, which, in towns remote from natural water supply, means a very important item in the running expenses.

"The *hot water* system alluded to is the invention of Mr. W. E. Prall of New York, and consists in employing water heated to a high temperature, say about 400° Fahr., which is not allowed to evaporate into steam until it enters the building where it is to be used. At times when very little is being used, but that little still at a high temperature, as for cooking purposes, the flow of water is kept up by means of specially designed pumps, which maintain a continual circulation. This system is now being laid down in New York city. The late Mr. Max Hjortsberg of Chicago, chief engineer to the Chicago Burlington and Quincy Railway, also put down about a mile of 2½ in. pipe on this plan, with a result so satisfactory to himself that he declared in favour of water as against steam. The temperature of the water at the end of the mile was only 2 degrees less than at the boiler, working at about 160 lbs. pressure. The water was conveyed to a factory, where, after the pressure had been reduced, the steam evolved was used for driving an engine, and the unevaporated water for heating the rooms, returning afterwards to the boiler for further use."

on p. 80, "In compressed-air machines the losses of pressure due to incomplete expansion, cooling, and waste spaces, play an important part. In water-pressure machines loss does not occur from these causes." He disagreed with this as to the waste spaces; if these could be done away with in engines worked by water-power, they would have more efficient machines than at present.

Mr. W. E. Rich said he observed no remark in the paper upon the best pressure to use, in machinery for the transmission of power by compressed air. He believed he was right in saying that the experience of most engineers who had used compressed air, and had looked into the question carefully, was that, if the size of the pipes and air engines was not a serious hindrance, low pressures were most efficient. It was natural that it should be so. If they used dry air compressors, and did not attempt to cool the air as it was compressed, about 30 lbs. per sq. in. was a good pressure to use for works on the surface of the ground. The efficiency of air-compressing machinery working continuously, so far as he had tested it, was low: and it was much more applicable to intermittent action than to continuous action. The ports of air engines were very liable to become choked by ice if they were kept running constantly. He had removed the inconvenience in one instance by putting a small fire under the ports; but had heard recently that glycerine used as a cylinder lubricant was an antidote, as it prevented the adhesion of ice to the metal surfaces. The author had given some experiments in reference to the loss by friction in air pipes, which were very welcome to engineers, for there was very little information in the way of practical experiment upon the subject.

With reference to the question of water engines, he thought it was pertinent to remark upon the great inconvenience and difficulty in working with slide-valves in water engines. The slide-valve was the part of a water engine that usually gave the most trouble. In the first place, if they expected an engine to work occasionally and to stand occasionally, it was necessary to make both the valve-face and the valve of gun-metal; and a gun-metal valve working on a gun-metal face in water was one of the most likely combinations for setting up

abnormal friction. They had better content themselves with a cast-iron face and a gun-metal valve, and balance the pressure on the face of the valve. In many cases it was better to have a cylindrical valve, and to put up with some waste. A water engine to give the best results should be designed with a long stroke, large cylinder capacity, and low speed in revolutions or strokes per minute. A large air-vessel should always be provided close to the engine on the supply pipe, and the cylinder should have a small air-vessel in connection with each end.

Mr. A. Paget said that, as M. Achard had been prevented from being present owing to family affliction, no doubt the members would excuse a departure from the usual procedure, to allow M. Achard to give an answer in the Proceedings on this and other points. He fully shared in Mr. Schönheyder's and Mr. Mair's difficulty as to the vacuum under the belt; the real effect of great speed appeared to him to be the exact contrary of what had been stated.

Mr. E. B. Ellington said a remark had been made by a previous speaker that it was a wonder there were no systems of transmitting power for public use in England. He wished to say that such a system had been in operation in Hull for the last three or four years, on the principle of using hydraulic power, transmitted through mains laid along the streets, and distributed by branch pipes as required (*see* a paper by Mr. Henry Robinson, Proc. Inst. C.E., vol. xlix. p. 1, and also the Transactions of the Liverpool Engineering Society, vol. i.).

The President was sorry that the author was not present to reply to the several questions that had been asked, and also to defend some of the statements he had made; but the report should be sent to him, and he would be able to insert his reply in the Proceedings. On some points the paper was perhaps not as full as it might have been. There were omissions, for instance, in reference to the application of hydraulic power at Hull, and also in reference to the conveyance of power through long distances for pumping, by means of flat-rods, as

in Cornwall.* Something also might be said as to the use of steel ropes. The author had spoken of nothing but iron wire, whereas light hard-drawn steel wire was no doubt much better. He proposed a vote of thanks to M. Achard for his paper, which was carried unanimously.

M. ACHARD, replying by letter to the remarks made in the discussion upon the paper, explained that the failure of the attempts to supply motive power at Bellegarde and Fribourg was due to their lacking the most important conditions of successful working: the mere fact of having cheap power available not being enough to make up for the deficiency of those conditions. The suggestion referred to by Mr. Fernie by no means met the case. Wherever a working population congregated, amusements suitable for their entertainment would be sure to follow fast enough of their own accord; their absence was the effect, not the cause, of dearth of workpeople.

The doubt he had expressed at the outset of the paper (p. 57), as to the attainment of practical success in large undertakings for distributing power to a number of factories, was confirmed by the experience gained at Schaffhausen; notwithstanding that there the circumstances were much more favourable than at either Fribourg

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* This method was adopted on a very large scale, in the case of the old Wheal Friendship Mine at Marytavy in Devonshire, for the transmission of power from large overshot water-wheels to pumps fixed in the shaft of the mine, at a considerable distance higher up the valley. The largest water-wheel was 52 feet diameter and 12 feet breast, and its ordinary speed of working was 5 revolutions per minute. The length of stroke given by the crank to the horizontal or "flat" rods was 8 feet; the rods were round wrought-iron, $3\frac{1}{2}$ inches diameter, and were carried on cast-iron pulleys. These particulars have been furnished by the kindness of Mr. Richard Taylor, who states that in the instances he has known of the use of flat-rods in Cornwall the amount of power conveyed was much smaller, the rods being of 2-inch round iron.

At Devon Great Consols, near Tavistock, there are altogether very nearly 3 miles of 3-inch wrought-iron rods, carried on bobs, pulleys, and stands, whereby power for pumping and winding is conveyed along the surface to different parts of these extensive mines, from eleven large water-wheels ranging up to 50 feet diameter, to which water is brought along $8\frac{1}{2}$ miles of leats of 18 feet width.

or Bellegarde. Schaffhausen possessed an industrious population accustomed to labour, and the power supplied from the Rhine by the works erected for that purpose was readily taken up. Moreover the founder of the enterprise, the late M. Henri Moser, had presented a large part of the requisite capital as a free gift, so that the amount paying dividend was only about £32,000. In spite of these advantages, and of excellent management, the concern had never paid more than 2 or 3 per cent. on its share capital; and in some years, owing mainly to heavy repairs, there had been no dividend at all. At Zurich, which again was essentially a manufacturing town, the municipality had for some years past distributed, by means of ropes, power obtained from the river Limmat as it flowed out of the lake; but he was informed on good authority that this undertaking had been a very costly one, and was bringing in very small profits. These two examples therefore were not very encouraging.

Turning to Geneva, the conditions were far from being so favourable as they were at either Zurich or Schaffhausen. Manufacturers were less enterprising there; wages were high; and the workpeople were used to light handicrafts requiring taste and accuracy, and were not of the class needed for heavy trades. At the present time there were many owners of water-wheels along the banks of the Rhone who could find no one to rent the power they had to let.

The water-pressure at present let out in Geneva for working small machines in houses and shops was not supplied by any private company, as Mr. Fernie had stated, but by the town itself through the ordinary water mains; the pressure was only $4\frac{1}{2}$ atm. (67 lbs. per sq. in.) at the outside. It would be advantageous if this department of the water supply to the town could be extended; since at Geneva almost the only way of effecting a useful distribution of power was by multiplying small ramifications or subdivisions.

With reference to the project mooted some years ago for utilising on an extensive scale the current of the Rhone, where it flowed out of the lake of Geneva, the fall available from that point down to the confluence of the Arve was nothing like so much as 25 or 30 ft. In the interest of properties bordering on the lake, the outflow of the Rhone ought to be so regulated as to keep the flood waters down to a

proper level; and the result would then be an available fall ranging from 5 to 7 ft. only. Owing to the small difference of level even as at present existing, the high floods that occurred in the Arve had the effect of more or less drowning the water-wheels along the banks of the Rhone above the confluence. Had the project been carried into effect, it would have proved no eye-sore to Geneva; and the reason of its falling through had nothing to do with the beauty of the city or neighbourhood, but was due to a difference as to terms. A further attempt in the same direction was in contemplation; but he did not know whether circumstances were now more favourable for its realisation, and it would be hard to predict the result.

The statements given in pages 60 and 61 of the paper, respecting the use of wide driving belts for transmitting large amounts of power, were derived entirely from a report drawn up by Herr Max Radinger for the Austrian Commission at the Philadelphia Exhibition in 1876. He must refer Mr. Schönheyder and Mr. Mair to that report as his authority, not having himself had any opportunity of becoming acquainted with that branch of the subject.*

In reference to the most advantageous pressure to employ in machines worked by compressed air, it had been mentioned on page 74 of the paper that, in the absence of satisfactory means for reheating the expanding air, it was from a low pressure, not exceeding 4 atmospheres, that the highest useful effect was obtained. The reasons, which would readily be understood, had been fully entered into in his original articles in the "Annales des Mines," seventh series, vol. vi., pp. 335–8.

He was surprised it should have been thought by Mr. A. Siemens that too much importance had been attached to the question of efficiency. In any general examination of the transmission of power, without reference to any individual application, it seemed to him the very first consideration was that of efficiency; but he had not failed to point out how this consideration might itself be outweighed by others, as soon as particular instances came to be dealt with.

As to the absence of loss from waste spaces in water-pressure

* See also Cooper on the Use of Belting, p. 53.

machines, as commented on by Mr. Mair, of course there would necessarily be a loss if the water filling the waste spaces were allowed to escape at each stroke of the piston; but if this water were prevented from escaping, there would be no loss of power, because as soon as ever the communication with the pressure pipe was opened again, the full pressure would be restored to the water left in the waste spaces.

Notwithstanding Mr. Schönheyder's remarks about water-piston air-compressors, which however had now almost fallen into disuse, he adhered to the opinion that the alternating movement imparted to the water at each stroke of the piston was attended with a loss of power. There was a distinction between power expended in imparting velocity to the water, and power expended in producing the rise and fall of the water-level in the two upright chambers at the ends of the horizontal cylinder. The rise and fall no doubt counterbalanced each other without any loss of power. But the velocity imparted to the water in one direction in the forward stroke was evidently incapable of serving to produce the velocity in the contrary direction in the return stroke; it could only become transformed into eddies, and ultimately into heat, so that the equivalent work was totally lost. What took place in such compressors might be compared with what would occur in the case of a single-acting pump delivering direct into a water main without the intervention of an air-vessel: the inertia of the column of water in the main would then have to be overcome at every stroke.

In reference to the use of steel wire-ropes for the transmission of power, he would remark that steel was by no means a material of uniform quality. Whilst soft wrought-iron approached very closely to chemically pure iron, steel contained more or less of carbon, and sometimes of phosphorus, and varied greatly both in its chemical composition and in its molecular structure. On this account care had to be exercised with regard to many of the applications that might be made of it; this was the case with respect to its use for the construction of boilers, and the same would be true for wire-ropes. At the time of his first taking up this subject, steel was altogether out of favour in Switzerland for wire-ropes, as used for transmitting

power; but progress had been made since then, and steel wire-ropes were now coming more and more into use. The result of experiments made at Zurich, as he understood from Mr. G. Naville, of Messrs. Escher Wyss and Co., was that steel wire-ropes should be of the same diameter as those of iron, and would then last rather longer; a rope running continuously night and day would last from 200 to 250 days if of iron, and from 250 to 300 if of steel, thus about compensating for the difference in cost. Moreover steel ropes stretched less in working than iron, so that a steel rope running continuously would have to be shortened up only once in 120 days, against twice in the same time for an iron rope. A letter from Mr. D. H. Ziegler, of Messrs. T. T. Rieter and Co., Winterthur, expressed a more decided preference for steel ropes, from the experience of recent years; and recommended particularly the Creusot mild steel, made especially for the manufacture of wire. It added that the pulleys for steel wire-ropes need be no larger in diameter than those for iron ropes.

With respect to transmission of power by water pressure, as at Hull, and by flat-rods, as in Cornwall, these were methods peculiar to England; and he had therefore not thought it necessary to enter into them in a paper presented to English engineers, who had so much better opportunities than himself of becoming acquainted with the particulars.

ON MACHINES FOR PRODUCING COLD AIR.

By Mr. T. B. LIGHTFOOT, of Dartford.

In bringing before the Members of this Institution the following paper upon the Mechanical Cooling of Air by successive compression, cooling, and expansion, the author, while not pretending to give a complete theoretic explanation of the various processes, considers it necessary to premise his description of the machines in use, by a few general remarks upon the behaviour of air under such circumstances. The subject will therefore be treated under the following heads:—

1. General remarks upon the cooling of air by successive compression, cooling, and expansion, and upon the deposition of its contained moisture.

2. Short notice of some machines which have previously been devised for producing cold air.

3. Description of the machines designed by the author.

4. Remarks as to the application of such machinery to commercial and other purposes.

1. General Remarks on the Cooling of Air.

When atmospheric air is rapidly compressed under a piston, without either loss or gain of heat from without, it is raised in temperature, mechanical work expended on the piston being transferred to the air in the form of heat. If this compressed and heated air, at that pressure and temperature, be then introduced below another piston, and expanded without loss or gain of heat from without down to its original pressure, it will also resume its original temperature, and will have given back, while expanding, useful work precisely equal in amount to that absorbed during compression. If however, after compression, the air is first cooled,

by allowing some of its sensible heat to be absorbed by some cooler substance, and is then expanded under a piston to atmospheric pressure, a less amount of useful work will be given back than in the first case, and the air, after expansion, will be found to occupy less than its original volume, and to be colder than its original temperature by a difference which is greater or less, according as the quantity of heat taken away before expansion is large or small.

The operation just described forms the basis upon which the cold air machines to be treated of in this paper are constructed. In its simplest form it is shown graphically in Fig. 1, Plate 14, where A B represents a volume of atmospheric air (considered, for the sake of convenience, as a perfect gas) at a temperature of 52° F. This air is compressed under a piston to the volume C D, according to the adiabatic curve B D. The pressure A C above the atmospheric pressure is then, in the present example, 50 lbs. per sq. in., or 65 lbs. absolute; and the temperature is 321° F., giving a rise of 269° F. Now suppose that, instead of immediately expanding the volume C D of hot compressed air back to atmospheric pressure, we first abstract a portion of its sensible heat, and so reduce its temperature to 52° F.; it will then be found that its volume is also reduced to C E, where C E bears the same ratio to C D as the new absolute temperature bears to the old; or (taking − 461° F. as the absolute zero of temperature) C E : C D : : 513 : 782.

On now expanding the volume C E to its original atmospheric pressure, the piston will be pushed out only to the position G, and the final temperature of the air will be 125° below zero F. The efficiency of the operation is represented by

$$\frac{\text{Volume swept through by expansion piston}}{\text{Volume swept through by compression piston}},$$

and the area B D E G gives the theoretic mechanical force required for driving the machine.

This force will of course be greater as the extent of compression is greater; but, on the other hand (assuming the temperature of the cooling agent, which is generally water, to be constant), the cold produced by expansion will be correspondingly greater.

Commencing then with the simple fact, that air is heated by compression, and is cooled to a like amount by expansion, it next becomes of importance to ascertain how far the presence of water, in the condition either of steam or of mist or of actual liquid, affects the heating or cooling of air, and the conditions of working any given apparatus: in addition to its effect in the formation of ice, which is very objectionable.

The important fact to be noted in this connection is that air at constant pressure, having free access to water, will hold a different quantity of water in solution as vapour or steam, at each different temperature; or conversely, the temperature of the "*dew point*" for any body of air varies with the quantity of water held in solution by it. The hotter the air, the more water can it hold without depositing (see Fig. 2, Plate 14, and Table appended).

Thus if air is highly heated, and water is then admitted to it in the form of spray or injection, it will take up much more water before becoming saturated than it could have held before it was thus heated. Again, if air under compression, and saturated with vapour, is allowed to expand, a large quantity of its contained vapour will condense and freeze into snow, thereby yielding up a quantity of heat to the air, which air is in consequence cooled less in expanding than it would have been, had it been dry air to start with. This freezing is also a serious practical evil, from the deposition of ice about the valves and in the air passages, which necessitates frequent stoppages even in small machines. An appreciation of these facts will render it easy to understand the action of the various machines about to be referred to, in which much depends upon the presence of water in the air at different times.

Various means have been devised for ridding the air more or less completely of its contained moisture, by employing some chemical material, such as chloride of calcium or sulphuric acid, which is a powerful absorbent of water. But in the author's opinion the use of such chemicals as are known to him is inadmissible, except perhaps for small machines or for those working under special conditions, because of the trouble which would be experienced in changing the drying material, and in evaporating off the water it has absorbed, so as to render it again fit for use.

Before passing on to the machines in which the cooling takes place by mechanical means, it will be well to show briefly how far the theoretic diagrams are modified in actual practice. In addition to the adiabatic curve B D, Fig. 1, Plate 14, is shown the isothermal curve B E for the compression of a perfect gas, from atmospheric pressure and 52° F. temperature, up to 65 lbs. per sq. in. absolute pressure. The former of these is the curve which would be produced if the air could be compressed instantaneously, or without transmission of heat; and the latter the curve which would be produced if it could be compressed without raising its temperature at all. The curves obtained in practice of course fall between the two; the nearer they approach the isothermal line the better. The full line B J is a copy of the actual compression curve, in a diagram taken with a Richards indicator from the compression cylinder of a machine made by the author's firm, and illustrated in Figs. 5 to 9, Plates 15 and 16. The initial temperature of the air entering the cylinder was 52° F.; and it contained, as ascertained with a hygrometer, 0·007 lb. of aqueous vapour to the pound of mixture, this being about 88 per cent. of saturation for the observed temperature. By calculation from the volume, the temperature at the end of the stroke was 267° F.; whereas, if the compression had been accomplished adiabatically, it would have been 321° F.

The air thus compressed is delivered to the cooling apparatus, consisting in this case, as shown in Fig. 7, Plate 16, of an arrangement of small brass tubes, having cold water flowing through them. The air, passing round the outside of the tubes, is thus reduced in temperature to within from 5° to 10° of the initial temperature of the cooling water; and with this abstraction of heat, its capacity to retain vapour being lessened, a portion of the moisture it contains is condensed, and may be collected and run off if suitable means be provided. In practice, with the machinery under the conditions mentioned above, the air, if cooled to 70° F., may be made to part with about one-half of its contained moisture at this stage.

In Fig. 3, Plate 14, are shown the adiabatic and isothermal lines of expansion, E G and E B respectively. The volume C E is the same as the volume C D in Fig. 1, corrected for reduction of temperature and for deposition of vapour. The intermediate full line E N shows as

before the actual curve of expansion in an indicator diagram taken from the machine shown in Figs. 5 to 9. This curve, as might be expected, never falls to the adiabatic line, owing to gain of heat from without, and to the heat given off in the condensation and freezing of the moisture. In this case the final temperature was calculated at 82° below zero F.; whereas the temperature of the air expanded adiabatically would be 113° below zero F.

In the foregoing description no notice has been taken of any special means for causing any further deposition of moisture than takes place in the cooling apparatus; this point will be treated further on.

2. Short notice of some of the Machines previously devised for producing Cold Air.

Kirk's machine* consists in principle of a single horizontal cylinder, in which air is compressed at one end and expanded at the other. The heat caused by compression is partially carried off through the cylinder cover, which is water-jacketed, and the cold from expansion is used to abstract heat from a current of brine or other medium, circulating over the cover at the expansion end. Between the two ends is a regenerator, formed of several thicknesses of wire gauze. Through this both the hot compressed air and the cold expanded air pass, on their way from one end of the cylinder to the other; so that there is a continual alternate compression and expansion of the air, and a continual heating and cooling of the regenerator.

Mr. Kirk has informed the author that one of his moist-air machines, in use at Hong Kong, produces regularly 1 ton of ice for a consumption of 5 cwts. of English coal. This performance will be found on calculation to indicate a very high efficiency.

The machine however hardly comes under the category of those described in this paper, since the cooled air is used only for abstracting the heat from some medium not in direct contact with it, and cannot be itself discharged for use. For this reason the machine itself is

* Earlier forms of this machine are fully described in a paper by Mr. Kirk, Proc. Inst. C.E., vol. xxxvii., p. 244.

more economical than those in which the cold air is directly made use of; for the air, being used over and over again, assists in keeping down the temperature of compression, and thus reduces the amount of mechanical work required. It will hereafter be shown how the same principle may be applied to other cold air machines.

The Giffard cold air machine consists of one single-acting water-jacketed compression cylinder, and one single-acting expansion cylinder; both are vertical and worked from cranks on an overhead shaft. The compressed air is led from the cylinder bottom into the cooler, which is merely a cluster of small tubes placed vertically in a case. The cooling water passes upwards outside the tubes, and thence goes to the compression-cylinder jacket; the air is admitted into a casing below the ends of the tubes, passes up through them, and is taken off from the top to a wrought-iron reservoir. A pipe from this reservoir supplies the air to the expansion-cylinder; the admission and exhaust being controlled by two independent steel mitre-valves in the cylinder bottom, worked by cams from the shaft.

In this machine no attempt is made at drying the air; all the moisture taken into the compression cylinder is discharged in the form of snow from the expansion cylinder, with the exception of the portion deposited in the cooler owing to the partial cooling of the compressed air.

M. Giffard uses a special form of piston packing, made of two layers of india-rubber, the outer one hard and the inner soft. This packing, which is altogether about $\frac{3}{8}$ in. square in section, is inserted in a groove turned in the piston; and small holes, drilled from this groove to the underside of the piston, admit the air-pressure to the back of the ring, thus making a similar joint to the ordinary cupped leather.

Windhausen's machine expands air under a piston from its ordinary atmospheric pressure; the cooled and expanded air is discharged much below the atmospheric pressure, either through tubes surrounded externally by brine, or into a hermetically sealed chamber, where the objects to be frozen are placed. After this

process the air is again compressed to atmospheric pressure, cooled, and re-expanded. The disadvantages of this machine are the large size of the cylinders, &c., necessitated by the very low pressure employed, and the fact of its depending for its action entirely on the production of a partial vacuum.

The Bell-Coleman refrigerator consists of an ordinary machine for producing cold air by compression, cooling, and expansion, combined with an apparatus for depositing a portion of the moisture before the air is admitted to the expansion cylinder. In this system the air is partially cooled during compression by the actual injection of cooling water into the compressor, and by causing the current of compressed air flowing from the pumps to come in contact with a spray of water. From the pumps the mixed air and water is led by pipes into a chamber or chambers with perforated diaphragms, which catch a portion of the suspended moisture. The air, still in its compressed state, and cooled to within 5 or 10 degrees of the initial temperature of the cooling water, is then led to the expansion cylinder through the interior of a range of pipes, or other apparatus, with extended metallic surfaces, cooled externally to a lower temperature than that of the cooling water; so as to induce a further reduction in temperature and consequent deposition of moisture. This extra cooling of the compressed air is effected either by allowing the cold expanded air, before it reaches the chamber to be cooled, to come in contact with the outside of the range of pipes, or by exposing these pipes to the spent air passing from the cold chamber.

This system is objectionable at sea, from the corroding action of the salt water upon the cylinder, pistons, valves, &c.; particularly when, as must often be the case, the machine lies idle for several days. Again, with internal injection there is a decided loss of efficiency, wherever it is possible to use the same air over and over again; which can be done by making the cold chamber into a comparatively air-tight compartment, and drawing from it the supply to the compression cylinder. With an external system of cooling the compressed air, full advantage is gained by this arrangement; for the expanded air discharged into the cold chamber, even if it be not

passed through a dry air machine, becomes practically free from moisture, when discharged in the usual way through some kind of trap for collecting the particles of snow. This air, being continually compressed and expanded, free from all contact with water, ensures economy in working, firstly, by utilising what may be termed the waste cold, and secondly by excluding water vapour, which otherwise would have to be condensed and deposited, with a consequent loss of power. Thus, after a few cycles of operation, the whole of the moisture is removed from the air, which works thenceforward like a perfect gas. With internal injection, on the contrary, though the waste cold can be utilised, there still remains a continual loss from the saturated condition in which the air, even if used over and over again, must necessarily be delivered from the cooling apparatus on each occasion.

The difficulties in working this machine as a dry air refrigerator may be further seen by considering its performance in a tropical climate, where, even at sea, the water available for cooling the compressed air would probably have an initial temperature of 90° F. Under the most favourable circumstances the compressed and saturated air would then be delivered to the cooling pipes at a temperature of at least 95° F., the pressure being say 65 lbs. per sq. in. absolute. Without taking into account any water mechanically suspended in the air, the quantity of aqueous vapour contained in it under these conditions would be 0·008 lb. to the pound weight of pure air. Now, as there is precisely the same weight of dry cold air circulating outside the cooling tubes in a given time, as there is of warm compressed air within, it follows that, by whatever amount the temperature of the internal air is reduced, by an equal amount must that of the external air be raised. But in addition the internal air has vapour mixed with it, which, as the temperature falls, gives off heat, measured not only by the reduction in its sensible temperature, but by the latent heat of vaporisation; and this heat also has to be taken up by the external air. It is found by calculation that, assuming each pound of internal air, with its proportion of vapour, to be reduced to 42° F., the pound of external cold air, which has to take up all the heat due to this reduction, will be raised in temperature by 84° F.

Instead of using the spent air for cooling purposes, the cold air from the expansion cylinder may be applied direct to the cooling apparatus; but in this case difficulty would be experienced from the deposited moisture inside the tubes actually freezing from the intense cold of the external air, a difficulty which the author understands has often occurred with this apparatus. This, apart from the mere obstruction of the pipes, would involve a further sacrifice of cold, owing to the liberation of the heat of liquefaction.

It should however be stated that these machines have been worked successfully in cases where a large amount of cooling water at low temperature is available, as, for instance, on board an ordinary Atlantic steamer. There is no doubt that moderately dry air would be obtained, wherever a sufficient supply of water at 45° F. or 50° F. can be had.

Sturgeon's Refrigerator is a horizontal machine, with some novel arrangements as regards the construction of its air-valves and pistons. The compressed air is first cooled partially, by being passed through tubes surrounded by cooling water; and is then passed through charcoal or some other absorbent of moisture, before being admitted to the expansion cylinder. If the charcoal or other material is properly changed and renewed when necessary, this may form a dry air process; but, as already stated, the introduction of a chemical dryer is in the author's opinion undesirable, except under special conditions.

Messrs. Hick Hargreaves and Co., of Bolton, manufacture cold air machines of horizontal form, in which the Corliss cut-off gear is applied to the admission valves of the expansion cylinder. The air is compressed in a double-acting cylinder, into which cooling water is injected at each stroke; it then passes through a series of receivers, in which the water mechanically carried over is deposited; and it is finally admitted to the expansion cylinder, and expanded down to atmospheric pressure. So far as the author knows, no attempt is made at drying the air, which passes to the expansion cylinder fully saturated for its temperature and pressure; but a

large snow-box, consisting of a series of baffles, abstracts the bulk of the snow from the cooled air, after expansion and before its introduction to the cold chamber. In a machine of this description which the author has seen, the snow had to be cleared out from the exhaust valves every few hours.

3. Cold Air Machines manufactured by the Author's firm.

The first of these machines, Figs. 5 to 9, Plates 15 and 16, was designed to deliver about 15,000 cub. ft. of cold air per hour, when running at 60 rev. per minute. It is really a modified Giffard machine, having been manufactured under that patent. The air is taken into the water-jacketed compression cylinder C by the inlet pipe A, and is delivered through the pipe B to the cooler D, containing 170 horizontal $\frac{1}{2}$ in. brass tubes of 54 in. length, arranged in five nests, through the inside of which the cooling water is caused to circulate from above downwards. Fig. 7, Plate 16, is a longitudinal section of this cooler. The compressed air travels upwards amongst the tubes, as indicated by the arrows, meeting cooler and cooler water as it ascends; until finally, after being brought down to within 5° or 10° F. of the initial temperature of the cooling water, it is discharged into the reservoir G, Fig. 6, formed in the same casting as the cooler D. The vapour condensed during the cooling gradually separates from the air while in this reservoir, and finding its way to the bottom is run off at intervals by cocks provided for the purpose. The pipe I, Fig. 6, conducts the cooled and partially dried compressed air to the expansion cylinder E, where it is expanded down to atmospheric pressure, and is then discharged cold through the delivery pipe J. The admission and delivery valves in the bottoms of the compression and expansion cylinders are shown in Figs. 8 and 9, and are all of the mitre type. The delivery valves for the compression cylinder are six in number, in two clusters of three valves each; and the rest are single valves worked by cams on the main shaft. The angles of the cranks are adjusted so as to give the best turning effect; and the difference between the power absorbed in compression and that given off in expansion is made up by a pair

of horizontal steam cylinders H H, Figs. 5 and 6, which also overcome the frictions &c. of the apparatus.

Indicator diagrams from the compression and expansion cylinders are shown in Figs. 18 and 19, Plate 21; these are the same that have already been taken for comparison with the adiabatic and isothermal curves.

The following Table gives the result of test experiments made with this machine at Dartford:—

Volume of Cold Air delivered per hour, at atm. pressure,	15,000 cub. ft.
Weight of Air delivered per hour	1620 lbs.
Diameter of compression cylinder	27 ins.
„ „ expansion „	22 ins.
Stroke of each	18 ins.
Revolutions per minute	62 revs.
Air pressure in receiver (absolute)	65 lbs. per sq. in.
Temperature of air entering compression cylinder (containing vapour up to 88 per cent. of saturation)...	52° F.
Temperature of air discharged from compression cylinder	267° F.
Temperature of compressed air admitted to expansion cylinder	70° F.
Temperature of air after expansion	82° below zero F.
Work done in compression cylinder, from diagram	43·12 H.P.
Work given off in expansion cylinder, from diagram	28·05 H.P.
Difference between work done in compression cylinder and work given off in expansion cylinder	15·07 H.P.
Diameter of steam cylinders	12 ins.
„ „ trunks in „	10 ins.
Stroke of trunks	15 ins.
Initial steam pressure in cylinders (absolute)	55 lbs. per sq. in.
Work given off in steam cylinders, from diagram	24·6 H.P.
Initial temperature of cooling water	57° F.
Final „ „ „ „	145° F.
Quantity of cooling water passing per minute	9·25 lbs.
Work lost in heat carried off by cooling water	19 H.P.

Figs. 10 and 11, Plate 17, show the arrangement of a smaller machine, of similar construction to that just described, except that the cooler consists of only two nests of tubes D D. The compressed air is led by the pipe B to the first of these nests, and then over the diaphragm L to the second, and so to the expansion cylinder. The

main shaft is carried by standards K K fixed on the cooler; and the driving power is a single vertical steam cylinder H, standing between them. This machine gave exceedingly good results, and was shipped to Australia.

Neither of the foregoing machines was intended to produce dry air; and it is now necessary to explain the dry air process devised by the author. This process depends for its action on the varying vapour capacity of air at different temperatures; but instead of the transfer of heat being accomplished by contact with cold metallic surfaces, involving large apparatus and difficulties from the formation of ice, it is effected by the act of expansion itself. The partially cooled compressed air, which, when the machine is taking its supply direct from the atmosphere, will always be fully saturated with vapour for its temperature and pressure, is introduced into a small primary expansion cylinder, and is there expanded under a piston, to such a pressure as gives a final temperature of about 35° F. The result is the condensation of almost the whole of the contained vapour, which is discharged, in the form of mist, with the air, into an apparatus having surfaces so arranged that the mist is deposited on them as water, falls to the bottom, and is drained off. The dried air, still at a high pressure, is then admitted to a second and larger expansion cylinder, in which it is expanded down to atmospheric pressure; and it is finally discharged cold and free from moisture.

As an illustration, assume that compressed air at 95° F. and 65 lbs. per sq. in. absolute pressure, fully saturated with vapour, is introduced to the primary expansion cylinder. Each pound of air will then contain 0·008 lb. of vapour. To cool this mixture of air and vapour down to a temperature of 35° F. will require a ratio of expansion of about 1·75 to 1, the pressure being reduced thereby to about 35 lbs. per sq. in. absolute. The 0·008 lb. of vapour per lb. of air will now be reduced to 0·0016 lb., owing to the lessened vapour capacity, or lower dew point, of the air; the difference, or 0·0064 lb., being condensed into water, and collected in a suitable receiver. On admitting the dried air to the second expansion cylinder, it will expand to atmospheric pressure in almost exactly an adiabatic curve;

and each pound of cooled air, as it is delivered from this second cylinder, will only contain about 0·001 lb. vapour in suspension. The difference between this amount and the 0·0016 lb. admitted from the water collector, is discharged as snow, and caught in a snow-box. Both these amounts together are however so small, that the air is practically dry; in fact, on exhausting the cooled air, with this moisture and snow in it, direct from the machine into the atmosphere at 50° F., only the slightest trace of mist is visible.

Fig. 4, Plate 14, is a diagram giving a comparison of the two systems for depositing moisture: one by extra cooling of the moist compressed air by means of the cold expanded air acting through metallic pipes; and the other by utilising the expansive action of the air itself, on the author's plan. Here C D represents the volume of the air, at 95° F. and 65 lbs. per sq. in. absolute pressure, as it leaves the first cooler; C E is the volume when it has been cooled at constant pressure to 42° F. by the external application of the cold air, during which process heat is given off sufficient to raise the temperature of an equal weight of the dry cold air by 84° F.; E G is the adiabatic curve of expansion, and E J the actual curve, allowing for the effect of the moisture still remaining in the air at 42° F. The final temperatures for these curves are respectively 127° and 120° below zero F. On the other system D K is the curve of expansion down to a temperature of 35° F.; the pressure is then reduced to 35 lbs. per sq. in. absolute, and the moisture deposited is the same as in the first case, after cooling at constant pressure to 42° F. The condensed vapour having been abstracted, and the dried air admitted to the second expansion cylinder, K N is the curve of expansion to atmospheric pressure; while D B is the line of adiabatic expansion from the point D. The final temperatures are 68° below zero F. for K N, and 96° below zero for D B.

It thus appears that with the plan of cooling before expansion the final temperature of the expanded air is lower than in the author's system. But the effective temperature in the former case is really much above the final temperature, because the heat given off in liquefying the vapour has all to be taken up from outside by the expanded air. On the other hand, when the condensation

of the vapour is accomplished during the act of expansion, the cold expanded air has no further function to perform, and can be wholly utilised for any desired purpose. Besides this the work returned to the machine in expansion is less in the first case than in the second, in proportion as the area L C E J is less than the area L C D K N.

The following Table gives the calculated relative amounts of vapour condensed and deposited, in the various stages of cooling, with a machine on the author's system, capable of delivering 15,000 cubic feet of cooled air per hour, and dealing with air in a tropical climate, having an initial temperature of 90° F., and fully saturated with vapour.

	Lbs. per hour.		Per cent.
Total weight of vapour entering with the air		45·36	100·00
Deposited as water in cooler	33·61		74·10
Deposited as water after first expansion	9·26		20·40
Discharged as snow in cooled air	0·93		2·05
		43·80	
Balance, being residual vapour still existing in cooled air		1·56	3·45

In Figs. 12 and 13, Plate 18, are shown end and side elevations of a dry cold air machine on the new system, manufactured at Dartford. Being originally intended merely as an improved form of the 15,000 c. ft. machine already described, without any special drying apparatus, the arrangement of the expansion cylinder with its gear is not as compact as it would have been, had the machine been designed from the first with a view to the dry air process.

The compressed air is delivered by the pipe A to the cooler, where by means of diaphragms it is caused to circulate among the tubes, meeting colder and colder water, until it passes to the upper compartment B, ready to be taken to the expansion cylinder through the pipe C, Fig. 12, in which is a baffle grid for catching any condensed moisture that may still be in suspension. The expansion cylinder, Fig. 14, Plate 19, has a trunk piston, the annulus of which is used for the first expansion, and the full piston area for the second. After being expanded on the annular side so far as to reduce its temperature to

about 35° F. (the grade of expansion being regulated by an adjustable slide), the air is passed through the pipe D, Figs. 12 and 13, containing the grids E, to the depositing vessel K, which acts as a water collector and pressure regulator. In this vessel the vapour condensed in the cooling during expansion is gathered, and run off at intervals. From this receiver a pipe G conducts the dry air to the lower valve-chest, whence it is admitted to the underside or full area of the piston, expanded to atmospheric pressure, and discharged at a low temperature. Two steam cylinders H H supply the necessary driving power.

For cooling the air during compression, a separate supply of fresh cold water is used in the cylinder jacket, the result being that the temperature is easily kept down to about 230° F.; whereas in the experiments before described, where the water which had passed through the cooler was sent through the compression-cylinder jacket, this temperature was 267° F.

The machine when tried at Dartford worked exceedingly well, and in every way realised its intended duty. The air was discharged quite free from moisture, though it was being delivered to the first expansion in the annulus at a temperature of 92° F., and would consequently contain a considerable proportion of vapour.

Indicator diagrams from this machine are given in Figs. 20, 21, and 22, Plate 22: Fig. 21 shows the first expansion in the annulus, and Fig. 22 the final expansion under the full piston area; the horse-power, calculated at 60 revs. per min., was 40 HP. in the compression, 8 HP. in the first expansion, and 13 HP. in the second. The diameters of the compression and expansion pistons are 27 in. and 20 in. respectively, the stroke in each case being 18 in. A second set of indicator diagrams from the same machine is shown in Figs. 23, 24, and 25, Plate 23.

A horizontal dry cold air machine for marine purposes, one of several now being constructed, is shown in Figs. 15 to 17, Plates 19 and 20. It is intended to supply 5,000 cubic feet of cold air per hour, when running at the rate of 65 revs. per min. It has a double-acting compression cylinder C, with gun-metal liner

forming the water jacket; this material being employed in preference to cast iron on account of its greater conductivity. This cylinder discharges the air, compressed to about 65 lbs. per sq. in. absolute, into the series of coolers B B B, which are made on the same tubular principle as those already described; thence it passes to the expansion cylinder E, with trunk piston, shown in section in Fig. 16. Each end of this cylinder is fitted with distinct adjustable cut-off valves. The intermediate water depositor and air vessel D, Fig. 17, is shown in vertical section in Fig. 15. The baffles in this depositor consist of a number of grids G, placed at an angle: an idea for which the author is indebted to Mr. E. A. Cowper. A jacketed steam cylinder A, with adjustable cut-off, supplies the necessary driving power. The disposition of the cylinders in this machine was arrived at and decided upon after very careful consideration of the turning moments about the shaft centre, a number of different combinations being taken. For larger machines the arrangement of cylinders would be somewhat modified, depending upon the number of each kind employed, and also upon whether the engine was simple or compound.

4. Application of Cold-Air Machines.

First in importance in this relation is the question of preserved meat. This not only affects ourselves at home but also many of our colonies. To show its magnitude, a Table is appended, showing the number of cattle and of sheep in the different colonies of Australasia, for the year 1879. The cost of producing each head of cattle is about £4 sterling, and at present the price realised as often leaves a loss as a profit. If however, by transport under refrigeration, a new and practically unlimited market could be opened out, and the graziers could receive even one penny per pound more than they now realise for the carcases, the increased annual profit would be enormous, not to mention the immense boon to consumers at home.

The question of ventilation is also of very great interest; for if dry cool air could be introduced into our public buildings, the benefit would be great, both as regards health and comfort; and

the same applies still more to the cooling of dwellings in hot climates, such as India. In manufactures the production of ice, the condensation of gases, the cooling of liquids, the moderating of temperatures in cellars &c.; and on board ship the ventilation of holds and cabins, and the cooling of saloons and engine-rooms in hot climates, are all instances where the application of these machines would be advantageous. The object of this paper however has been chiefly to show that satisfactory machinery can be made for this purpose; and that by a very simple process, involving no complication in apparatus or in principle, the air can be delivered at once cold and perfectly dry.

In conclusion the author wishes to express his obligations to his partner, Mr. E. L. Beckwith, for assistance rendered in the preparation of this paper.

APPENDIX.

Table giving weights of aqueous vapour held in suspension by 100 lbs. of pure dry air when saturated, at different temperatures, and under the ordinary atmospheric pressure of 29·9 ins. of mercury. (Partly abstracted from "A practical Treatise on Heat," by T. Box; partly calculated by the Author).

See Fig. 2, *Plate* 14.

Temperature.	Weight of Vapour.	Temperature.	Weight of Vapour.
Fahr.	Lbs.	Fahr.	Lbs.
−20°	0·0350	102°	4·547
−10°	0·0574	112°	6·253
0°	0·0918	122°	8·584
10°	0·1418	132°	11·771
20°	0·2265	142°	16·170
32°	0·379	152°	22·465
42°	0·561	162°	31·713
52°	0·819	172°	46·338
62°	1·179	182°	71·300
72°	1·680	192°	122·643
82°	2·361	202°	280·230
92°	3·289	212°	Infinite.

N.B.—The weight in lbs. of the vapour mixed with 100 lbs. of pure air at any given temperature and pressure is given by the formula

$$\frac{62 \cdot 3\ \mathrm{E}}{29 \cdot 9 - \mathrm{E}} \times \frac{29 \cdot 9}{p},$$

where E = elastic force of the vapour at the given temperature, in inches of mercury (to be taken from Tables)

p = absolute pressure in inches of mercury

= 29·9 for ordinary atmospheric pressure.

Table for Adiabatic Compression or Expansion.

Absolute Pressure.		Absolute Temperature.		Volume.	
Ratio of greater to less. (*Expansion.*)	Ratio of less to greater. (*Compression.*)	Ratio of greater to less. (*Expansion.*)	Ratio of less to greater. (*Compression.*)	Ratio of greater to less. (*Compression.*)	Ratio of less to greater. (*Expansion.*)
1·2	·833	1·054	·948	1·138	·879
1·4	·714	1·102	·907	1·270	·788
1·6	·625	1·146	·873	1·396	·716
1·8	·556	1·186	·843	1·518	·659
2·0	·500	1·222	·818	1·636	·611
2·2	·454	1·257	·796	1·750	·571
2·4	·417	1·289	·776	1·862	·537
2·6	·385	1·319	·758	1·971	·507
2·8	·357	1·348	·742	2·077	·481
3·0	·333	1·375	·727	2·182	·458
3·2	·312	1·401	·714	2·284	·438
3·4	·294	1·426	·701	2·384	·419
3·6	·278	1·450	·690	2·483	·403
3·8	·263	1·473	·679	2·580	·388
4·0	·250	1·495	·669	2·676	·374
4·2	·238	1·516	·660	2·770	·361
4·4	·227	1·537	·651	2·863	·349
4·6	·217	1·557	·642	2·955	·338
4·8	·208	1·576	·635	3·046	·328
5·0	·200	1·595	·627	3·135	·319
6·0	·167	1·681	·595	3·569	·280
7·0	·143	1·758	·569	3·981	·251
8·0	·125	1·828	·547	4·377	·228
9·0	·111	1·891	·529	4·759	·210
10·0	·100	1·950	·513	5·129	·195

TABLE SHOWING NUMBER OF CATTLE AND SHEEP IN AUSTRALASIA.

Name of Colony.	Area. Sq. Miles.	Estimated Population, 1879.	No. of Cattle in 1879.		No. of Sheep in 1879.	
			Total.	Per Inhabitant.	Total.	Per Inhabitant.
New South Wales . .	310,937	714,012	2,914,210	4·1	29,043,392	40·6
Victoria	88,198	888,500	1,129,358	1·3	8,651,775	9·6
South Australia . . .	380,070	255,087	266,217	1·0	6,140,396	24·1
Queensland . . .	669,520	214,180	2,800,633	13·1	6,065,034	28·2
Tasmania	26,215	111,208	129,091	1·2	1,834,441	16·5
Western Australia . .	1,000,000	28,668	60,617	2·1	1,109,860	38·7
Total . .	2,474,940	2,211,655	7,300,126		52,844,898	
New Zealand . . .	105,342	448,124	578,430	1·3	13,069,338	26·9
Total for Australasian Colonies	2,580,282	2,659,779	7,878,556		65,914,236	

Discussion.

Mr. Lightfoot wished to add that the machine shown in Figs. 15 and 16 was now at work in Upper Thames Street, in connection with a chamber of 7,500 cub. ft. capacity, intended for the preservation of meat and fish. Figs. 23 to 25, Plate 23, were copies of indicator diagrams taken from that machine. The temperature at the end of the compression was 240°, and that of the expanded air was about 55° below zero F. The drying apparatus acted admirably, the snow discharged in the cooled air being no more than calculation would show.

In the discussion on M. Achard's paper, on the previous day, Mr. Rich had mentioned the difficulty arising from the accumulation of ice in working compressed-air engines. It occurred to him that his plan of double expansion, with intermediate depositor, would entirely obviate that difficulty, while adding very little to the cost of ordinary compressed-air motors.

Mr. W. Schönheyder said there was a statement at the commencement of the paper, that when atmospheric air was *rapidly* compressed under a piston it was raised in temperature. He was aware that a few people did hold that opinion, namely that it was necessary to compress air rapidly in order to get a rise of temperature. It was now well known however that a rise of temperature took place whether the compression was rapid or slow. Of course the practical point was that in the case of slow compression the temperature fell almost as soon as it was raised, the heat being carried away by conduction, and therefore the rise could not be measured; but the heat was generated just the same.

As he had happened a few years ago to carry out some experiments upon one of the early Giffard machines, it might be interesting to give a few of the particulars then obtained. He had taken indicator diagrams which were very similar to that shown in Fig. 18, Plate 21; but in that machine the cooling was effected by the injection of water,

which he quite agreed with the author was objectionable; and the effect was that the curve was kept very low, coming very nearly to the true isothermal curve of compression. The result of the injection of water was that a large amount of moisture was carried over into the cooling chamber, and a large quantity of snow was deposited, with a diminished efficiency of the machine. The temperature of the air discharged from the compression cylinder, as estimated, was 131° F. The diagram from the expansion cylinder had a very similar appearance to that shown in Fig. 19. The estimated temperature of the air discharged was — 80° F.

In page 110 of the paper was described a packing which M. Giffard applied, about $\frac{3}{8}$ in. square in section, and kept against the cylinder by the pressure of the air from behind. That was a very objectionable plan, inasmuch as it caused an enormous pressure between the cylinder and the ring, much greater than was required. He had made some approximate experiments to ascertain the amount of power required to move the piston against the friction thus produced, and it was enormous. If it was borne in mind that for each HP. expended in friction there was something like 2,565 units of heat liberated, it would be seen that this power was not only wasted in useless friction, but also caused an immense addition of heat to the cylinder, which was of course detrimental. Therefore the packing of such pistons should work as freely as possible, and its pressure ought not to be increased by the pressure of the air from behind.

He did not know whether the first machine of Giffard was well known. It was rather smaller than the one mentioned on page 115. The compression cylinder was $22\frac{7}{8}$ in. diam., and the expansion cylinder $20\frac{1}{2}$ in. diam. The stroke was $13\frac{3}{4}$ in., and it worked at 72 revolutions per minute. The temperature after compression was 131° F., and the pressure was then 55 lbs. per sq. in. absolute. The HP. shown in the compression was 24, and in the expansion 14—nearly the same proportion as that mentioned by the author; so that it gave rather more than half the power back again in the expansion cylinder. On account of the mode of injecting water, there was a rather larger quantity, 72 lbs., used per minute. The rise of temperature was very small, only 14°.

He could not understand the last figure in the Table, page 115, where the author stated that the heat taken off by the cooling water only amounted to 19 HP., as compared with 43 HP. in the compression cylinder. The heat taken off in the experiments he had carried on represented 23·6 HP., and the work in the compression cylinder was 24 HP. Those figures agreed better together than the figures mentioned by the author. The whole of the heat given out in the compression cylinder should be shown in the water, or very nearly.

He understood that the machines were more especially made for use on board ships in cooling meat, and no doubt they were admirably adapted to that purpose. He did not think however that they would ever be economical machines, as they required a large amount of fuel. The author had referred to the cooling effect of the Kirk machine at Hong Kong, which produced four tons of ice from one ton of coal. That was a much higher value than he had himself seen attached to it. He understood that it really produced very little more than a ton of ice for a ton of coal. Be that as it might, with other systems of producing ice it was possible to get 9 tons of ice with a ton of coal. This class of machine therefore could never be economical for cooling purposes. In addition the author had shown an engine for driving the machines, which was unjacketed, and was as uneconomical as could well be constructed. While the most economical engines of the present day used 16 lbs. of water per HP., that engine would probably use 60 lbs. or more. On shipboard that would be a very great consideration, and he did not see how it was possible to justify a construction so uneconomical. It also appeared to him from Fig. 13, Plate 18, that the crank-shaft was very weak for its work; and certainly the overhang, where it was attached to the expansion cylinder, was very ugly.

Mr. W. A. Gorman wished to endorse the opinions expressed by Mr. Schönheyder. Having had twenty-two years' experience in ice-making machinery, he had found that with the ether ice-making machine 1 ton of coal would produce 4 or 5 tons of ice, whereas with the Kirk machine he always understood 1 ton of coal produced only

2 tons of ice. With regard to the machine mentioned by the author as having been working at Hong Kong, he thought the consumption of fuel stated must be incorrect; and he believed it had been superseded by an ether ice-making machine, on account of the cost of its fuel.*

Mr. T. R. CRAMPTON said that a comparison of the quantity of coal consumed with the amount of ice produced was rather misleading, unless it was stated what kind of engine was used. If it were stated that so much power was used for a given weight of ice produced, it would be left for the engineer to decide how he would get that power. The engine shown, which was unjacketed, could certainly not be worked under 6 or 7 lbs. of coal per I.H.P.

Mr. D. JOY thought that they were rather confusing the aim of the author's engine, and that of the engine with which it had been compared. The author's engine was intended to cool air, not to make ice; and it could hardly be compared with machines the special function of which was to make ice. They would not think of comparing a compound surface-condensing engine for driving steamers with some very simple high-pressure engine used where there was no need to care about the consumption of coal. Nor should they in this case allow a confusion to arise, to the manifest detriment of the engine under discussion.

Mr. J. MCFARLANE GRAY had been struck with the paper as well considered and very interesting, and had no doubt that it would

* Mr. A. C. Kirk has since requested the insertion of the following note, in correction of this statement:—Some eight years ago Messrs. Kyle and Bain took out to Hong Kong a 5-ton ice machine, the second of my moist-air machines that was made; and some years later they added one of my earlier dry-air machines for occasional use. They drove an ether machine out of the field; and as the Tudor Ice Company could not compete with them, they bought their ice stores and business. In the hands of Messrs. Kyle and Bain, both thorough engineers and well acquainted with the machines and the trade, the manufacture of ice at Hong Kong has been a complete commercial success.

lead many members who had not yet paid attention to such machines to take more interest in them. He rather looked at the subject from the point of view of Mr. Joy. Taking the case of steamers, there would be a small engine of 40 HP. for cooling, and there might be alongside it an engine of 2000 HP. Now a little saving of steam in the small engine, by adding to its weight and increasing the complication, might be really uneconomical. Simplicity and compactness were of great importance on board a steamer; and mere economy in respect of fuel in such machines was not, and perhaps never would be, of the highest importance.

The author appeared to be right in his remarks about the theory of the machine, but he would suggest that the diagrams should show the line LM for pressure equal to zero (Fig. 1, Plate 14), as well as the line AB for atmospheric pressure, and the line LC for volume equal to zero. The character of the curve was then made more clear, and calculations could more readily be performed with it.

Mr. R. PRICE WILLIAMS quite agreed with Mr. Joy in questioning the comparison between an ice-making machine and a refrigerating machine. The question of refrigerating machines had a most important and direct bearing in connection with food supply. Having recently given some special attention to the subject, he had been very much impressed with the gravity of the question of the future meat supply for the country. He had in his hand a letter from Sir William Armstrong, acknowledging the receipt of a recent paper of his own on the question of the increase in the population of this country, from which, with the President's permission, he would read the following extract: "I find it deeply interesting not only as affecting the question of the duration of coal, but also as regards the future food of the nation. What a fearful thing it will be if in future ages the food supply of the country from foreign sources should be intercepted!" He would add, what a fearful thing it would be if, having regard to the rapid rate at which the population was increasing, the food supply of the country, from whatever source derived, should ever prove insufficient! He must say that he looked to machines of that kind as supplying at the moment a very great

want. All who had studied economical questions had realised the gravity of our depending for daily food upon the produce of foreign countries, and more especially in regard to the supply of meat. He did not think the economical value of the machines should be estimated as lightly as Mr. Schönheyder had estimated them. He had not been able to gather from the paper sufficient data to estimate what the cost of the engines might be, but they appeared to be in every way exceedingly efficient; and he could not help thinking that they would direct attention to a most important subject—the means of quickly and safely providing the necessary food supply of the country.

The PRESIDENT believed that Mr. Lightfoot had brought before the members the particulars of the first machine made with the recent improvements. When several more had been made, no doubt the author would be able to quote an exact price. The last machine promised to be a great improvement upon the previous ones, on account of the arrangement made to cool air down to about 35°, so as to deposit as much water as possible before the final expansion; thereby getting dry air, and also a greater degree of cold for a given amount of horse-power.

Mr. SCHÖNHEYDER asked leave to say that, if there was no objection to comparing a machine for producing ice with a machine for producing cold air, he could give a correct comparison. A Siddeley machine would abstract about 15,000 units of heat per indicated horse-power when cooling water through moderate ranges of temperature, and when making ice only about 3,000 to 4,000 units; the Giffard machine with which he had experimented abstracted only 1,000 units per indicated horse-power, and the machine mentioned in the paper about 1,600 units. That, he thought, was a perfectly correct comparison.

Mr. LIGHTFOOT said, in reply, that Mr. Schönheyder had drawn attention to what was perhaps a rather weak expression at the beginning of his paper. He did not hold that air required to be

rapidly compressed in order to be heated; he had used that expression, in order that it might be understood that the air was compressed adiabatically, or nearly so; because, if the compression was very slow, the specific heat of the air being so low, the cylinder would run away with all the heat. With regard to M. Giffard's packing, of course the use of it in the machines made by his firm was not of their own deciding. The type of engine to be used could be varied according to circumstances; and they were quite prepared to supply compound engines for machines of a larger size, or even for the size required for giving 15,000 cub. ft. per hour. Of course they were very much in the hands of the buyer. He could not put in compound condensing engines at the price of simple ones. With regard to Mr. Schönheyder's doubts about the statement in page 115, as to the amount of heat taken off by the cooling water during the experiments with the 15,000 cub. ft. machine, that statement was quite correct. It was impossible that the heat equivalent of the total horse-power shown by the compression diagram could be taken up by the water, because a portion of that horse-power was expended on work done in discharging the air from the cylinder after compression, and on friction &c. It seemed to him clear that some mistake must have been made in the experiments carried out by Mr. Schönheyder, in which the heat taken off by the cooling water was given as equal to 23·6 HP. against 24 HP. in the compression cylinder.

In reference to the remarks of Mr. McFarlane Gray, he was quite willing that the theoretical diagrams should show the line of absolute zero of pressure, as in Figs. 1, 3, and 4, Plate 14. In comparing theoretical diagrams with actual diagrams one naturally took the same base line for both, namely the atmospheric line; and that was the only reason for the omission of the zero line. He would not say anything about the cost of making ice, because the machines were not intended for that purpose. Of course if the ether machine were to be used for producing cold air, it would require to be supplemented by another machine, which would supply the air and project it against the cooling surfaces; and that would add very much to the expense and complication, and also to the cost of working.

The PRESIDENT wished to ask one question. Why was the ice so objectionable? If the temperature in the chamber was intended to be kept at 33°, or anything above freezing point, would not the ice passed into the chamber cool the air in the chamber? Was it the moisture that was objectionable?

Mr. LIGHTFOOT said it was immaterial whether there was ice or not, so far as the mere cooling of the chamber was concerned; it was the freezing up of the passages &c. that was the evil. If the machine could only be made to work satisfactorily with the ice, the dry-air apparatus would be unnecessary.

The PRESIDENT observed that there had been many compressed-air machines already invented, and many of these had been used for cooling purposes, oil-distilling, &c. The preservation of meat however seemed to be a reason for their being increased in number to a very large extent, there being now a very great demand for machines to cool the air, in order to bring meat to this country. Thus the subject was a generally interesting one; and he was sure the members would wish to pass a vote of thanks to Mr. Lightfoot for bringing it before them in so full and able a manner.

The vote of thanks was passed unanimously.

ON STONE-DRESSING MACHINERY.

By Mr. J. D. BRUNTON and Mr. F. TRIER, of London.

It has been for some time the desire of the authors to introduce to the notice of the Members of this Institution their Machines for Dressing and Turning Stone: but they have delayed doing so until now, because they wished first to perfect the details; and especially to be able to say that they had practically mastered Granite, that most difficult of stones to deal with. The machines now to be described have undergone the test of practical working; and have been pronounced to be good, serviceable, labour-saving machines, by persons who have used them for some time past, and are using them still.

Much ingenuity has been put forth, and numerous attempts have been made, to shape or dress stone by mechanical means; but no attempt will here be made to describe the various machines that have been devised. Suffice it to say that, saws being excepted, they for the most part aim to do the work by means of chisels of some form or other, applied either to chip or to scrape away the irregularities of the stone. It is at this point that the authors' machines diverge from the beaten path, and take hold of a new principle of action; the action, namely, of circular rotating cutters, operating by rolling to chip off from the stone the inequalities of its surface.

This constitutes the elementary principle; and may be stated as a rolling pressure brought to bear at the base of a certain projecting portion of stone, with the intent to force it off. The great power of such a pressure to effect the desired object is due to the fact that its incidence at any given moment (or what may be called the *tread* of

the cutter) extends over a very small space; and that upon this small space the whole force in exercise is concentrated. It remained to contrive such a mechanical arrangement as should successfully apply this principle.

We have in stone a material composed for the most part of particles hard enough to cut and wear away the hardest steel; but held together by a cohesion relatively far feebler than that which holds together the molecules of steel or chilled cast iron. Hence it will be evident that in attacking such a substance by a metal tool, it is of the first importance that *attrition* be avoided. If this enters in any considerable measure into the conditions of the contest, the metal will be worsted: but if it be a question of simple pressure, the stone will inevitably be overcome.

The first application of the principle was to the turning of stone, especially granite. The simplicity of this application was due to the circumstance that the constantly revolving stone presented a continuous surface for attack; and the contact of the edge of the rotating cutter with the surface was therefore unbroken. The cutter, once set in motion by contact with the stone, continued rolling; and, being placed at an angle of about 25° to the axis of the stone, chipped the surface away incessantly in a spiral line, as the slide-rest and tool-holder moved along the bed of the lathe. Nothing more was needed. The concurrent revolutions of the stone and the cutter reduced attrition to a minimum, and considerable speed of surface rotation was attainable. With two cutters, one on each side of the column, an inch and a half or more would be taken off in a single traverse. In fact, the work of a fortnight was brought within the compass of a day, while the character of the work produced was in every respect superior.

But when the authors came to deal with plane surfaces, many difficulties presented themselves. The contact of the cutters with the stone was necessarily intermittent. To accomplish a useful quantity of work speed was required: but to bring cutters into rapid rotation, by a contact with the stone which was made and broken at every moment, involved much attrition and consequent wear.

Although it may seem, as it does now to the authors themselves, a very simple remedy for this difficulty, *to drive the cutters*—in other

words, to give them mechanically an independent rotation, such that their edges should roll on the stone—yet this simple remedy was not thought of till several years had been spent in efforts to dress plane surfaces by simple contact. The machine, as represented in the drawings, is the offspring of this slowly-attained perception of what, in the shape of mechanical arrangement, the nature of the case demanded.

Fig. 1, Plate 24, is a section of the chuck or cutter carrier, showing the way in which the cutters are given a determinate rotation on their own axes, at the same time that they are carried round in a circle by the revolution of the carrier; their outer edges thus describing a circular path, which may be called the track.

The chuck A is a circular cast-iron box, bolted to the flange B of the horizontal hollow shaft C, on which it revolves. Into it are fitted the cutter spindles D; in number three, six, nine, or twelve, according to the size of the chuck. The cutters are fixed on their spindles by split nuts: each of these nuts for part of its length is shaped as a cone, which enters into the conical hole in the centre of the cutter. When screwed up the nut contracts, and grips the thread of the spindle, so that nut, cutter, and spindle become as one piece. On each spindle is keyed a bevel pinion E; and all the pinions contained in a chuck gear into, and are driven by, the central bevel wheel F: this is keyed on the central shaft G, which passes through the centre of the hollow shaft C, and receives its motion by means of the pulley H, Fig. 3. The chuck is driven by the pulley K.

The rates of cutter-rotation and of chuck-rotation are so adjusted relatively to each other that the cutter edge shall exactly roll in the track. For instance, in the case of a chuck having a track of 2 ft. diameter and cutters of 8 in. diameter, for every revolution of the chuck the cutters will make three revolutions.

Theoretically, with an exact roll of the cutter edge on the stone, there should be no attrition; and this is probably not far from being realised in practice. But coincident with the roll of the cutter, there is a forward movement of the stone, which is in fact *a rub*, distributed

over the edge of the cutter as it rolls; and to this it is probably due that there is any appreciable wear of the cutters at all.

The ordinary speed of a chuck is 300 to 350 revolutions per minute; the cutters themselves making 900 to 1050 revolutions in the same time.

The tread of a cutter, that is to say the length on its periphery that is in contact with the stone at any given moment, may be put at $\frac{3}{8}$ in. The duration of contact of any one tread will therefore be found by dividing one minute by the circumference of a 2 ft. chuck, multiplied by 300 revolutions, and divided by $\frac{3}{8}$; or by 60290. Thus in round figures the duration of contact is the thousandth part of a second; during which the advance of the stone will be less than the $\frac{1}{3000}$ part of an inch. The result of this small amount of attrition, and of its being distributed so rapidly and evenly over the whole circumference of the cutter, is that there is no perceptible heating, notwithstanding that the circumferential velocity of the cutters is about 2000 ft. per minute. Pulleys H of different diameters are provided for the central shaft G, to vary the speed of the cutters, as required by their diminished diameter consequent upon wear. The inclination of the cutters to the plane of the stone is 45°.

We have next to explain a refinement which is of great value; namely the placing the cutters in steps, or so as to cut in different planes. The authors in practice usually employ three planes; and for convenience the cutters may be called respectively X, Y, and Z, Z being the last or finishing cutter, as in Fig. 5, Plate 25.

Several important advantages accrue from this arrangement.

1st. The bevel of the edge of the finishing cutter Z may be made much more acute, because it has so little to do, and its face pressure against the stone is lessened in consequence. The acute edge of Z greatly facilitates the production of sharp arrises and unbroken corners.

2nd. The action of Z is to break away the stone which would otherwise be under the foot—so to speak—of Y, when Y next comes round; and of Y to do the like for X. Thus the face pressure of Y and X is also diminished, and the attrition still further reduced.

This effect is very perceptible in practice, both X and Y wearing to a square edge.

3rd. The arrangement renders "plucking" of the stone impossible. This point is illustrated in Fig. 5; it will be seen that a cutter taking, or, as perhaps better expressed, *lifting*, a heavy chip would be very likely to break away the stone below the surface, as shown at I. Cutter X does so; but Y and Z, following, obliterate these plucks, and *they* cannot pluck by reason of the overlying stone. A chip lifted by Y must necessarily break upwards, as along *a b*; and still more so a chip lifted by Z. It thus comes to pass that a stone exceedingly difficult to dress by hand without plucks (for instance Red Mansfield) can be dressed by this machine, taking a heavy cut, and yet producing a surface entirely unplucked.

4th. It becomes quite practicable by this method to take off at one operation the whole of the inequalities of an ordinary quarry scabbled stone. With this end in view the authors are now making machines with cutters placed in four steps, or even in more.

With regard to the material of the cutters, it has been found that for all kinds of sandstones, grit stones, and free stones, as well as for the magnesian limestones and oolites, chilled cast-iron cutters answer perfectly. They are chilled on the outer conical face, so that, as the cutter wears, and is ground on the lower edge or base of the cone, the cutting edge is always formed against the chilled surface. The endurance of these cutters is very satisfactory. In a six-cutter chuck, dressing from 40 to 50 sq. ft. of Newcastle grit per hour, the cutters will last seven or eight hours without changing. A cutter is ground in a few minutes, by means of an ordinary grindstone with a simple mechanical appliance, and is then ready for use again. A cutter will usually last for twenty such grindings before it is worn out. Its first cost is three shillings.

For hard limestones, steel cutters are necessary on account of the resistance presented by these stones: but the wear is quite insignificant. A set of cutters will last several days without changing. For granite also steel cutters are required. In the lathe a cutter will run for about ten hours without sharpening, dressing 250 sq. ft. of

granite once over. In dressing plane surfaces the wear, in the case of granite, is greater than in turning: but still moderate, the tool cost being less than that attendant upon hand labour. In dressing the softer kinds of stone, such as Newcastle grit, Bramley Fall, Dumfries, Red Mansfield, &c., the travel of the table is $\frac{1}{18}$ inch for each operation of a Z or finishing cutter. With a chuck of six cutters working in three steps, there are two Z cutters: therefore the table travels $\frac{1}{9}$ inch for each revolution of the chuck, or 36 in. per min., if the chuck makes 324 revolutions per min.

If a stone 2 ft. 6 in. wide and 4 ft. 6 in. long were to be dressed, a breadth of about 9 in. on each side would first be taken, and then a middle cut of 12 in. would finish it. Each cut would take, including the time occupied in raising or lowering the chuck, about 3 min., or say 10 min. for the whole stone, which has a superficial area of $11\frac{1}{4}$ sq. ft.; this is at the rate of about 65 sq. ft. per hour.

With stones 12 to 14 in. wide, which can be dressed in one breadth, 50 lineal feet are passed through and finished per hour; and much more might be done, if the machine were kept well supplied with stone. The labour connected with a machine doing this amount of work is performed by three men and a boy.

In order to produce a good arris, the axis of the chuck must be raised or lowered, so as to be two or more inches above the top or below the bottom arris, as shown in Fig. 6, Plate 25, at E and F respectively; and the stone should travel in such a direction that, the rotation of the chuck continuing always in the same direction, the cutters shall be running *off* the arris, and not *on to* it, in the way shown by the arrows at *e* and *f*.

A few words will suffice to describe the general construction of the whole machine, Figs. 3 and 4, Plates 24 and 25. S is the standard, having vertical planed faces, against which the saddle T is held by ordinary slides. This saddle is raised or lowered by the screw U, which is actuated by the pulleys P P. A is the chuck: the hollow chuck-shaft C is carried in bearings in a cylinder contained in the saddle T. The axis of C is tilted or inclined to the axis of the cylinder to the extent of $\frac{1}{32}$ inch in the foot, so as to give to the

chuck, and to the plane of rotation of the cutters, a slight inclination to the face of the dressed stone, for the purpose of back clearance. The cylinder can be turned round in the saddle by means of the handles L, so as to alter the direction of this inclination or tilt; and it can be moved out or in, so as to regulate the depth of cut to be taken off the stone. When the saddle and chuck are set for the work, the saddle is clamped fast to the standard by a turn of the screws M M, and the cylinder to the saddle by the screws N N: this secures rigidity. G is the central shaft, passing through the hollow shaft C, Fig. 1. On G is keyed the central bevel-wheel F, by which the absolute rotation is given to the cutters. Q is the table on which the stone to be dressed is fixed. R R are worms which gear into a rack under the table, and impart motion to it, being driven by the intermediate gearing V from the main driving pulleys. Two working speeds of travel in each direction are provided for, as well as quick return speeds.

Discussion.

Mr. TRIER wished to add that one of the great difficulties in connection with this machine was not merely the dressing but the supplying the machine with sufficient stone. To facilitate this, three worms were used, one under the middle of the table and one at each end, with corresponding worm rack under the table. The table was also provided with six small wheels, which ran on rails leading to and from the machine; and the arrangement included cross-trollies at both ends, and a return track. Thus several tables could be employed: as soon as the stone was finished, the table was run forward, the stone taken off, and the empty table brought round

by the return track, ready to receive another stone, and enter the machine again. For dressing flag-stones they had had nine tables running constantly, and the machine ran for two hours without stoppage. With flag-stones the edges were not dressed by the machine at all, but squared on the spot where they were to be used, because of the danger of breakage in carriage.

There was also another refinement to be mentioned, namely that the pinion on the spindle of each cutter was not keyed to the spindle, but it carried a clutch, which entered into a corresponding clutch on a ring keyed to the spindle, as shown at JJ in Figs. 1 and 2, Plate 24. In that way, if the cutter happened to be running rather too slow, there was play enough between the chocks of the clutches to allow it to be accelerated by contact with the stone. It could thus gain upon the driving pinion to the extent of an angle of 60°: but as soon as it left the stone it would begin to lose its quicker speed; the pinion would then overtake it and continue its motion at the old rate. But each time it came on to the stone it would be accelerated again for the moment.

The President asked if the machines had been used for dressing millstone grit, or any stone of equally difficult character.

Mr. Trier said there was one machine constantly at work on Newcastle grit: cast-iron cutters were used there, and the wear was very slight. The wear was very much greater with granite, the cohesion of the stone being so much higher. The length of time a cutter would work on granite without sharpening varied very much, not only according to the character of the granite, but according to the number of cutters in the chuck. As a rule they were changed after finishing from 10 to 16 sq. ft.

The President asked whether that was with granite taken fresh from the quarry.

Mr. Trier said that made no great difference. The granite he referred to was old, having lain about for a long time.

Mr. T. R. Crampton asked if there were any reliable data as to the relative cost of hand-labour and of the machine, under fair circumstances.

Mr. Trier said there had been several trials on this head. The machine had been employed in the enlargement of Stonyhurst College in Lancashire: there the cost of dressing by hand a square foot of the stone was about 6*d.*, and with the machine about 2*d.* That was with a good straight run of work, the machine being on the spot where the stone was to be dressed, and the stone being brought up to it and taken away from it with regularity. That stone was a hard gritstone: with granite the saving would be much greater. The cost given included labour in attending the machine, coal, interest on capital, and everything else.

Mr. R. Price Williams enquired where any of the machines could be seen working on granite; and whether anything but plane surfaces could be dealt with by the cutters.

Mr. Trier said that in Paris a large machine had been working on granite for six months; and one was now being made to be sent to Aberdeen for Mr. Fyfe. With the machine shown in the drawings, nothing but plane surfaces could be dressed; but the paper contained a short description of lathes for turning granite columns.

Mr. Price Williams asked if simple plinth work could be done, or if there would be any difficulty in cutting out a panel, for instance, in a stone.

Mr. Trier said that very small chucks could be constructed for the purpose of cutting large panels, but entrance would have to be made by hand first.

Mr. Brunton said that their lathes for turning granite had been in use for some years. Nearly all the columns now made were turned in them. They were used by Messrs. Macdonald Field & Co., Messrs.

Wright of Aberdeen, &c.; and especially by Messrs. Freeman of Cornwall (at whose works at Penryn they were seen by the members at the time of the Cornwall Meeting, Proc. 1873, p. 152). He had had a machine for flat surfaces at work on granite at Aberdeen some time ago; but it was not found to be strong enough, and it would be used for softer stone. A machine of a much more massive character was now in hand. They had not at first realised what was required in the way of massiveness. It was not a question of strength but of absolute solidity, to prevent anything approaching spring in the tool when at work. The machine in Paris was working satisfactorily on granite, and they would increase even upon its massiveness for Aberdeen. The Paris machine dressed millstones 5 ft. diam. and 4 in. thick, that were used for grinding chocolate &c.; probably some of them were for M. Menier's works. It had been found very difficult to dress those stones to perfectly parallel faces by hand: but a face of that sort, 5 ft. in diameter, was dressed in one pass through the machine in thirty or thirty-five minutes. Including the taking away of the stone, the changing of the cutters, and other things connected with them, one face was dressed every hour, whereas a man would take about five days. The area was 17 sq. ft., and it required a very good man to do $2\frac{1}{2}$ sq. ft. a day; so that in saying five days he was within the mark.

Mr. M. Powis Bale said it was stated on p. 136 that the circumferential velocity of the cutters was about 2000 ft. per minute. He presumed that with different classes of stone the speed would vary considerably. Perhaps the author could give the speed of the cutters acting on different stones, the angles of the cutters themselves, and also the angles at which the cutters acted on the stone, which were probably different for different classes of stone. In his experience of manufacturing stone-working machinery, the objection to many machines, where there was a large number of cutters at work together, was that they varied in wear. He should be glad to know whether the author had experienced any difficulty in that way: that is, whether with a large number of cutters the work produced was sometimes unequal. Thus, if there were six cutters, one

might be softer in its nature than the other five; it would wear faster, and then not only would the others have more to do, but the work would not be so good, especially if it was a finishing cutter that failed.

Mr. Brunton said they had tried various angles for the inclination of the cutter to the stone. They began with 22°, and went up to 30°, and they found that even then they had a face pressure greater than they liked. They then adopted 45° as a good working angle; and, as far as their present experience had gone, they had not found any reason to alter it with any kind of stone. They had worked with it upon Portland stone, French burr, granite, all kinds of grit, and hard limestone, and they had found it answer very well for them all.

With regard to the speed, he could only say the faster the better; but, as they were all aware, there were mechanical difficulties in the way of getting up enormous speeds: therefore when they had a speed of 300 or 400 revolutions per minute for the chuck they were satisfied. That would give about 2000 ft. per minute of circumferential velocity in the cutter.

As to variation in wear, it was true that if, as in the case of a chuck with six cutters, there were two finishing cutters, and one of them was altogether too soft, it would leave the other to do all the finishing work; and if the stone were examined, it would be seen that the marks were not quite equal, and the work would not be so perfect. That however was an accidental thing that seldom happened. Generally the cutters, being made of chilled iron, were very uniform; and they had rarely any complaint. The effect of any slight wear of one cutter more than another was very trifling, and was really invisible. Again, if there were a soft place in a cutter, it would never come round twice to the same spot; so that the effect was not perceptible. Practically it was found that the surface produced by the machine was finer than anything that could be produced upon stone except by rubbing. No hand-labour that could be expended upon it could produce anything like the perfection of the face, or of the arrises.

Mr. TRIER observed that the angle between the two faces of the cutting edge varied considerably with the hardness of the stone. They had sometimes used an angle of 90°; but in general they gave the roughing cutters an angle of 70°, whilst with the finishing cutter it was possible to use a much more acute edge, down to 20°.

Mr. J. W. COLE asked whether the machines had been used for dressing French burr stones; and if so, where they could be seen at work, and what success had been achieved. Had they been employed not only to shape the stones, but also to cut the radiating grooves technically known as the dress?

Mr. BRUNTON said that one of the machines was at work in France at St. Jouarre, where a vast number of French burr millstones were made, and they were cut with the machine perfectly well. There was nothing so hard as the French burr, and the cutters could take half an inch at once off these. A great speed was required —the greater the better. A slow machine would not succeed at all on such stone. They got a cutter circumferential speed of 2,500 feet per minute, and yet they never saw a spark, and the cutters did not heat. The practical difficulty was that the burr stones were so small and irregular in their form, almost like nodules, that it was very hard to fix them solidly in order to cut them. He was speaking merely of putting a smooth surface on the millstones, not of dressing them with the grooves, which had not been attempted.

The PRESIDENT proposed a vote of thanks to the authors for their interesting paper, which was passed unanimously.

ON THE FARQUHAR FILTERING APPARATUS.

By Mr. HENRY CHAPMAN, of London.

The main cause of the present difficulties experienced in the disposal of the sewage of large towns, is the failure to obtain an economic system of pure filtration for such enormous volumes of liquid. This is proved by the fact that, out of the numerous filtering processes, both mechanical and chemical, that have been tried, not one has been generally adopted; and even such important centres of civilisation as London and Paris continue to have their rivers polluted, and the health of their inhabitants injuriously affected, by the unfiltered sewage.

The reason of the failure of the various mechanical processes is easy of explanation. In all mechanical filters, whether by canvas discs, bags, cloths, or sand or other granular beds, the impure liquid is pressed against a porous material, the surface of which must be sufficiently fine to arrest the solid impurities, and allow only the pure liquid to pass away. When these solid impurities are of a slimy nature, as in sewage, the deposit on the filtering surface quickly becomes so impervious that the liquid is prevented from passing through it to the filtering surface, even though great pressure be employed. The filtering operation consequently soon comes to an end, and cannot be resumed until this deposit has been removed.

Owing to these repeated stoppages for cleansing, at short intervals, such an immense amount of manual labour, and such a large number of spare machines, or cloths, or filter-beds are required, to filter the sewage even of a small town, as render the cost of the filtration quite disproportionate to the advantages to be obtained by it.

It is therefore evident that, for a system of sewage filtration

to be successfully employed in an economic point of view, it is absolutely necessary that these frequent stoppages be avoided.

The principle of the Farquhar Filter is that of the continuous removal of the solid or slimy matters held in suspension in the liquid to be filtered, as they become deposited on the surface of a filter-bed during the process of filtration. The surface being thus continually freed from obstruction, rapid and continuous filtration is obtained.

Description of the Machine and Process.

The filter-bed F, Fig. 1, Plate 26, which is composed of sawdust or sand or powdered cinders or other suitable granular material, is contained in the closed cylinder W, and rests upon a coarse canvas or cloth, which is itself supported by a perforated plate, resting on a strong grating U at bottom of the cylinder W.

The liquid to be filtered is forced into the filter at the nozzle A, and passes down through the hollow screw spindle B direct to the underside of the cutter-plate S, where it is distributed uniformly through the three radial channels CC, Fig. 2, over the surface of the filter-bed F. The filtered liquid passes down through the filter-bed, leaving all its solid impurities on the upper surface, and finally issues from the pipe X.

During the process of filtration, the cutter-plate S is made to revolve by means of the pulley L and the bevel gearing attached, Fig. 1; and when desired is also caused to descend at any speed required, irrespective of its speed of revolution, by means of the feed-motion G.

In some cases the solid matters held in suspension in the liquid to be filtered are of a chalky nature, a thin deposit of which forms of itself a good filtering medium. In these cases it is only necessary to revolve the cutter-plate continually over the surface of the filter-bed in the cylinder W, and not to cause it to descend. The accumulating deposit will then be continually scraped off, and forced up the inclined plane of the saw-edged knife K, Figs. 1, 2, and 4, on to the top surface of the cutter-plate S, the under surface of which will always be kept free; and the supply of liquid will thus be continually in direct contact with the surface of the filter-bed.

In other cases the solid matters held in suspension in the liquid to be filtered are of a slimy nature, a thin deposit of which, if left on the surface of the filter-bed, would stop the filtration. In these cases it is necessary to cause the cutter to descend as well as to revolve, so that at each revolution of the cutter a very thin layer of the granular filter-bed will be cut up and scraped off, together with the slimy deposit adhering to it: thus producing at each revolution of the cutter a clean filtering surface on the filter-bed, and practically starting a new filter.

The speeds of the revolving and descending motions of the cutter-plate are determined by the amount of deposit required to be removed from off the surface of the filter-bed in a certain time.

When the cutter-plate has descended to within two or three inches from the bottom of the filter-bed, the descending motion of the cutter-plate stops automatically. The operation is then at an end, and the main portion of the filter-bed, which at the commencement of the operation was underneath the cutter-plate, will now be on the top of the cutter-plate, and intimately mixed with the solid impurities which it has arrested. If desired, the liquid remaining in the filter-bed at the end of the operation can be expelled at the pipe X, by means of compressed air forced into the filter through the centre pipe B.

To remove the fouled filter-bed, it is necessary first to unbolt the cover Q, Fig. 1, and to raise it to the position shown by the dotted lines, where it is held suspended by chains passing over pulleys and having counterbalance weights attached; the loose collar N being provided to prevent the packing in the stuffing-box from becoming disturbed by the thread on the screwed portion of the spindle B. Then, by means of the reversing gear R, the cutter-plate, which may have taken many hours, or even several days, to descend to the bottom of the filter-bed, can be made to revolve in a contrary direction, when it will quickly ascend the full pitch of the screw at each revolution, and the fouled filter-bed will, in a few minutes only, be automatically discharged over the top of the cylinder W. The cutter-plate and the cover Q together are then raised to a suitable height above the cylinder W, so as to allow of the cylinder being cleansed, and a fresh filter bed placed therein ready

for another process. The whole of the above operation for a large machine should not exceed one hour.

From the above it will be seen clearly that each time the cutter or scraper of the cutter-plate removes the solid impurities, and thereby frees the surface of the filter-bed from the impurities which would otherwise choke the filter and stop the filtration, a fresh filter is, to all intents and purposes, created. Thus it is evident that the removal of a thousand choked filtering surfaces, during one continuous process, is practically the creation of a thousand fresh clean filters.

Results of Working.

The length of time during which one filter-bed continues to filter depends upon the amount and nature of the solid impurities held in the liquid, and the depth of the filter-bed. The pressure required in the liquid also depends upon its nature, and upon the speed of filtration desired. On these points the following summary of experiments made in France will furnish a safe guide for calculations.

The filter-bed used during these experiments was only 25 centimètres ($9\frac{7}{8}$ in.) in diameter, and 25 centimètres in depth.

(1) At "Les Jardins d'Essai des Travaux de Paris," Asnières, near Paris, experiments were made on 27th August 1880, in the presence of M. Buffet, Ingénieur-en-chef des Ponts et Chaussées, and of Messrs. Durand-Claye and Locquet. The "eau des égouts," or town sewage, was filtered perfectly bright and continuously at an average speed of 6·25 litres (1·375 gallon) per minute, with a pressure of liquid equal to one atmosphere. When the pressure was increased to $1\frac{1}{2}$ atm., the speed was 8 litres (1·761 gallon) per minute.

(2) At the Dépotoir des Travaux de Paris, La Villete, Paris, experiments were made on 7th October 1880, in the presence of M. Duval, manager of the Dépotoir, and his assistants. On this occasion the "eau-vanne," or night soil, was filtered perfectly bright and continuously at the rate of 1·50 litre (0·33 gallon) per minute, with a pressure of liquid equal to one atmosphere.

This is admitted to be the most difficult of all liquids to filter. It has never been filtered continuously, previous to the above

experiment, and its filtration is one of the burning questions of the day on the Continent. It was then proved, to the satisfaction of the engineers and officials appointed by the French Government to superintend these experiments, that the machine was capable of separating the solid from the liquid, and that satisfactory filtration was obtained, as shown by the samples taken, which are now in the laboratory of the Ponts et Chaussées. And further, MM. Duval and Durand-Claye state, with reference to the experiment on the "eaux-vannes," that "at the beginning of the operation the filtering bed was 25 centimètres deep, and at the end was only 75 millimètres (3 in.) deep, and *the liquid still passed out clear.*"

In order to demonstrate practically, before the officials, the great advantage of the continual removal of the choked surfaces, the rotary motion of the cutter-plate was stopped in the middle of the above experiments, when the knife on the cutter-plate consequently ceased to scrape off and remove the impurities from the surface. Directly this took place the filtration rapidly diminished in volume, and in a few minutes it was totally arrested, though the same pressure of liquid on the filter-bed was maintained. The cutter-plate was then made again to revolve, and, as soon as the choked surface was cut off and forced up the knife on to the top of the cutter-plate, the filtration took place as rapidly as at the beginning of the experiment.

(3) At the Sugar Works of the Compagnie de Fives-Lille, at Coulommiers, experiments were made in the presence of M. H. Pellet, chemist to the Compagnie de Fives-Lille, and of the manager and engineers of the works. Beet sugar juice was filtered perfectly bright and continuously by the model machine, with bed $9\frac{7}{8}$ in. diameter, at the rate of 8 litres (1·761 gallon) per minute, with a pressure of liquid equal to two atmospheres. The filtration was continued for the space of four hours, and could have been continued for four hours longer, without changing the filter-bed or stopping the process, had it been desired.

The filtration was pronounced by the chemist, M. Pellet, to be perfectly pure, in fact as pure as if it had been made through blotting paper, and much better than the average filtration obtained from their ordinary press filters. M. Pellet also stated that he

saw no reason why a machine could not be constructed to filter continuously for four days. Their ordinary press filters act for only two hours and a half, after which they have to be taken to pieces.

The Compagnie de Fives-Lille, who have acquired the right to manufacture these machines in France, are now constructing a large apparatus.

(4) River water having clay and slimy matters in suspension, such as choke up all ordinary filters, is filtered perfectly bright and continuously by the model machine, having a filtering area of only 25 centimètres ($9\frac{7}{8}$ in.) diameter, at a rate exceeding 10 litres, or 2·2 gallons, per minute, under a pressure of one atmosphere only. Under a pressure of two atmospheres, the speed of filtration would no doubt be greatly increased.

Applications.

Sewage.—In this country there is no such difficult liquid to filter as the "eaux-vannes," which, according to French Government engineers, contain about twice as much solid matter as the ordinary sewage here. For this difficult liquid, and also for sewage, ordinary sawdust is found to be the best material of which to make the filter-bed. Owing to its light, elastic, and absorbent nature, it readily takes up and retains about eight times its own weight of the impurities arrested. It is very cheap, easily obtainable in large quantities, and, when surcharged with sewage matter, forms a valuable manure. It is however by no means necessary to the process that sawdust only should be used. If desired, powdered cinders or fine sand, both of which are valuable for clay lands, especially when mixed in the solid sewage, can be employed.

In the experiment at Asnières before mentioned, the sewage was filtered in the same black state in which it came direct from the main sewers of Paris; but before filtering the "eaux-vannes" it was found advisable to mix a small quantity (only 3 per cent.) of lime with the thick slimy liquid previous to filtration, as thereby greater speed was obtained than when filtered in its natural condition.

A very important advantage of this process for sewage is the solid condition, at the end of the operation, of the residuum absorbed by

the filter-bed. If, at the end of the operation, the remaining liquid in the bed is expelled, by means of compressed air introduced into the cylinder through the hollow screw spindle, previous to taking off the cover, the filter-bed and residuum form together a solid, and of course valuable, cake of manure, ready to be conveyed at once by road or rail to any part of the country, without having previously to undergo a drying process, with its great expense and serious objection in a sanitary point of view.

The cost of filtering the sewage of towns by this process should be nil, as it is computed that it will be fully covered by the price to be obtained from the sale of the sewage cake as manure. The speed of filtering the sewage at Asnières by the model machine, as already stated, was 8 litres or say 1·761 gallon per minute, through an area of $9\frac{7}{8}$ in. diameter, and with $1\frac{1}{2}$ atm. pressure. Therefore the speed through one square foot area is 3·31 gallons per minute; and an apparatus 10 ft. in diameter would filter 260 gallons per minute, or say 374,400 gallons per day of 24 hours. As the time occupied between the stopping of one operation and the commencement of another, in emptying the filter and renewing the bed, should not exceed one hour, it will be easy to estimate the number of machines that would be required to filter any given quantity of sewage to be operated on per diem.

Water Works.—For this purpose the apparatus will prove of great value. Firstly, from an economic point of view, the large filtering areas now employed, together with the necessary spare filter beds, all of which occupy much valuable land, would be dispensed with. Secondly, from a sanitary point of view, the water would not be exposed in large surfaces to the unhealthy action of the atmosphere, in or near large and densely populated cities. Lastly and chiefly, the filtration by this process has been proved to be much purer than anything obtained by the ordinary processes of filtration; in fact, again to quote the words of M. Pellet, "the filtration was as pure as if it had been made through blotting-paper," which is the recognised test of pure filtration.

In all the experiments referred to, samples of the filter-bed were carefully taken after the filtration was finished; and it was found, in

each case, that the portion of the filter-bed which had been cut up during the process of filtration was intimately mixed with the solid and slimy matters which it had arrested. Also that the portion of the filter-bed which had not been cut up was perfectly clean throughout, with the exception of its top surface only, which was coated with a thin deposit of the solid impurities: thus proving, beyond doubt, that the solid impurities did not penetrate below the surface of the filter-bed.

With a view to give some comparison between the cost of filtration with this process and with that employed by the Metropolitan Water Companies, the following extract from one of the official reports may be taken as a guide.

AVERAGE RATE OF FILTRATION PER SQUARE FOOT OF AREA PER HOUR.

New River Company	$2\frac{1}{2}$	Gallons.
East London Company	$1\frac{1}{3}$	,,
Southwark and Vauxhall Company	$1\frac{1}{2}$	,,
West Middlesex Company	$1\frac{1}{4}$	,,
Grand Junction Company	$2\frac{1}{8}$	,,
Lambeth Company	4	,,
Chelsea Company	2	,,

From the above it will be seen that the average rate of filtration is approximately 2 gallons per square foot per hour.

Taking the speed of filtration by the model machine (as before referred to) at 10 litres per minute, with a pressure of one atmosphere only, through a filtering area of 25 centimètres ($9\frac{7}{8}$ in.) diameter, the quantity per square foot area would be 18·8 litres, or say $4\frac{1}{8}$ gallons per minute, or $247\frac{1}{2}$ gallons per hour, as against 2 gallons per hour by the ordinary process now employed. From this calculation it follows that one machine 10 ft. in diameter should filter 466,530 gallons per day of 24 hours.

The construction of the machine being exceedingly simple, its first cost should not form a large item; and for the same reason the cost of maintenance should bear but a small proportion to the amount of work done. The speed of filtration in this machine is always constant, and no difficulty should be experienced in filtering waters containing fish-spawn or clay matter in suspension; whereas in the ordinary

sand filters the filtration diminishes daily as the surfaces become choked, especially when with slimy deposits. The washing of the filter-beds can be performed on the same system as that now employed at water works.

As these calculations are based upon the results obtained with a pressure of liquid equal to one atmosphere only, it is evident that, if a greater pressure were employed, within reasonable limits, an increased speed of filtration would be obtained, and this without detriment to the purity of the filtration; as was proved by the experiments at Coulommiers, where a pressure of two atmospheres was used.

Manufactures.—It will readily be seen that, in addition to water and sewage, this automatic self-cleansing process may be expected to effect a revolution in all kinds of filtration, and will prove of great benefit to sugar-makers, distillers, brewers, vinegar-makers, and others who require pure, rapid, continuous, and economic filtration. It entirely supersedes and dispenses with the use of cloths or bags, which entail a considerable annual outlay, and which do not produce an average pure filtration. For brewers and distillers it would be specially useful in filtering the refuse, which at present contains a very large amount of good liquid that is practically wasted, owing to the inability of any existing system to filter it continuously.

Advantages of Sawdust as a Filtering Material.

Taking bulk for bulk, it has been found that the following great advantages are in favour of sawdust, as against sand &c. :—

1. It is a cheaper commodity.

2. Its cost of conveyance is not a serious item, as it is with sand.

3. Much less manual labour is required in washing sawdust, chiefly on account of its lightness and portability.

4. It produces far purer filtration, because the grains of sawdust, when saturated, pack closely together, and the greater the pressure employed, the tighter the grains become knit together, which cannot take place with sand.

5. More than three times as much liquid is filtered in a given time, by this process, through sawdust as through the same bulk of fine sand. The reason is that the solid impurities are arrested immediately on the top surface of the sawdust, and are therefore instantly removed by the cutter, so that rapid and continuous filtration ensues; whereas with sand the impurities always penetrate some distance below the top surface, owing to the impossibility of making the grains of sand pack close enough together, even under great pressure. In fact the grains of sawdust tightly overlap one another under pressure, being thus equivalent to a number of pressed layers of fine cloths or blotting paper; and the sawdust bed is thus impervious to anything but pure liquid.

The question naturally arises, whether sawdust imparts any flavour to the filtered liquid, which with sugar &c. might be a disadvantage. The answer is that, after the liquid with which the sawdust has been saturated previous to filtration has been expelled, no flavour from the sawdust can be detected in the filtered liquid. The reason is that the liquid with which the sawdust was saturated is thoroughly absorbed into the loose grains of the sawdust like a sponge, and that the whole of this liquid is, under pressure, squeezed out of the grains, carrying with it the greater part of the flavour due to the sawdust. The sawdust being then in a compressed state, the filtered liquid is prevented from entering into the interior of the grains, and in its rapid passage between the grains it does not carry with it any flavour therefrom.

In all cases the sawdust must be saturated with some clear liquid, prior to making the filter bed, in order to create capillary attraction equally in all directions, so that the filtered liquid shall flow equally through the whole of the bed.

Repeated tests have been made to ascertain whether the liquid to be filtered drives before it the whole of the liquid used in the saturation of the bed prior to filtration. This has always been proved to be the case, by the following test. The amount of water used in saturating the bed has been carefully measured. So soon as this quantity had been extracted, and not till then, did the filtered sewage, or sugar juice, &c., pass out of the machine.

In conclusion the author wishes to express his thanks to Mr. John Frederick Cooke Farquhar, and Mr. Walter Oldham, the inventors of the process, for the assistance given in preparing this paper.

Discussion.

The SECRETARY said that Mr. Chapman, the author of the paper, was unfortunately prevented from being present by an important engagement with the French Government; but Mr. Farquhar and Mr. Oldham, the inventors of the process described, were present, and would take his place, as far as possible, in the discussion.

Mr. T. HAWKSLEY, F.R.S., might be able to give the members some information about filter-beds; but the particulars given in the paper really seemed to his mind so incredible that he should like to see the machine and study its operation before he gave any opinion upon it. With regard to the filtration of water for potable purposes, undoubtedly the great object in waterworks was to filter as slowly as possible, and not as fast as possible. There was a limit fixed at the present time to the speed of filtration, not for the reason that they could not filter faster, but for other, and he hoped better reasons; and this limit for many waters was, that only about 50 gallons should pass in 24 hours through each square foot of sand, 2 or $2\frac{1}{2}$ feet in depth. Unless they limited the rate of filtration in that way, the water was not perfectly purified. He was of course speaking here of river or reservoir water. With regard to spring water the case was different. They did not generally (though they had occasion to do so sometimes) filter spring water at all. But with

river or reservoir water, if they did not leave it for a long time in contact with the sand, the very fine particles of matter which were associated with the water did not become attracted to the facets of the sand. In the paper it seemed to be assumed that all those matters were deposited on the surface of the filter. There was no greater mistake. When the water had to bo purified to make it potable, it was necessary to extract those fine particles which by a mere mechanical process could not be extracted ; and the operation of filtration, as now understood, was a very different one from what it was formerly supposed to be. At first it had been assumed that the process was purely mechanical; whereas it was anything but mechanical. The fine particles not dissolved in the water, and some of the matters actually dissolved, were by slow filtration attracted to the facets of the sand, and there remained; and this went on after the water had passed from the surface, and even when it had reached some considerable depth in the filter-bed. Besides that, the vegetable and animal organic matters became burnt up to a very considerable degree by the process of oxidation which went on within the filter bed itself. It was a process of combination with the oxygen of the air contained in the water, and that was a very slow process. But with the machine now described the process was so rapid, that it would be quite impossible to accomplish more than the mechanical operation of detaining sensibly large physical particles on the surface of the filter. Therefore, ingenious as the process was, he had very little hope of its becoming applicable to the purposes of waterworks.

He did not deny however that for the detention of the much thicker and slimier matters of sewage the process would be effective, though he was afraid it would prove a rather costly one after all. He also thought that it might be applied to many manufacturing purposes—the charcoal process in the purification of sugar, for instance. There they would not need to work with the smallest possible pressure; while in the ordinary filter-beds of waterworks they did not allow more than 2 ft. head of pressure to exist. For that purpose they bent up the discharge pipe from the bottom of the filter-bed to a height which was only 2 ft. below the level of the water on the top

of the filter-bed. If when putting on a new filter-bed, or a newly cleansed filter-bed, they did not take that precaution, the water would run through six or eight times as fast as it ought, and then they found it was imperfectly filtered. But from the paper it would appear that the water in this process was to run thirty or perhaps fifty times as fast as it did at present; for the claim in the paper was that a very large operation was to be performed in a very small compass. So far as his experience went in the treatment of water for potable purposes, that would be a considerable mistake; and hence he did not believe that the process would be successful in any such application.

Mr. T. R. CRAMPTON said that the process proposed for dealing with sewage involved complete pumping machinery for lifting the sewage against the pressure of 1 atm. or more within the machine. The whole expense of that would have to be taken into consideration, but it was not mentioned in the paper. Even in the case of waterworks, the same thing would have to be done.

Mr. HAWKSLEY said that in that respect there was nothing new in the paper, because filtering water under considerable pressure had been the subject of many devices for the last thirty or forty years. But with respect to the continual scraping suggested, which was very ingeniously accomplished, he believed the method was new; though of course the scraping of filter-beds by hand labour was not. With regard to the material used, he might observe that sawdust would not answer if it was obtained from wood containing turpentine, such as pitch-pine or fir, or indeed from any wood capable of communicating taste or smell to the water.

Mr. F. NEWMAN wished to ask the author whether the process was applicable to the following case. Suppose there was a water supply to a town, which in ordinary circumstances did not require filtration, but that after the first summer rains an immense amount of clay was brought down in suspension, in a colloid form. In the special case he had in view, in South America, the water was in general sufficiently

pure; it had been analysed, and it contained only from four to six grains of impurity per gallon; but after the first floods it contained a great deal of clay, coming from large argillaceous deposits in the interior. They had the greatest difficulty in separating out this clay. The water had to remain three or four weeks in the reservoir to clarify itself, and an ordinary sand filter would be choked up in a day. Mr. G. Higgin had presented a paper to the Institution of Civil Engineers on the purification of water (Proc. Inst. C.E., vol. lvii., p. 272); and he had found that cinders made the best filter; the sharp angles seemed to intercept the matter better than anything else. It appeared to him that the application of sawdust would answer the same purpose as the cinders; and, taking it together with the cutting apparatus and the continual clearing of the surface, he was rather inclined to recommend the adoption of the process described. Still, like Mr. Hawksley, he should like to see it proved on a rather larger scale than had hitherto been attempted.

Mr. HAWKSLEY said that in the case described he had no doubt the process would answer, if the water did not bring down intermixed with the clay (as he was afraid it did) a considerable quantity of organic matter. In such a case it would, he presumed, be vegetable organic matter, because it came from a country which was very sparsely occupied, and was probably not cultivated at all. But even without organic matter it was scarcely to be expected that this rapid filtration would leave the water cloudless. There would, he apprehended from his experience, be a very slight and perceptible opacity, though perhaps nothing that would be objectionable in such a country. That was a difficulty with which they would have to deal; whereas if they filtered much more slowly that difficulty would not arise.

Mr. NEWMAN said the objection to the slow filtration was that it choked up the filters, and required such a large extent of filtering area. In the case he had mentioned there was still a slight cloud in the water, even after twice filtering through blotting paper; so that this could not be altogether avoided.

Mr. S. R. PLATT asked if the new system had been applied to filtering water that had been used for coal washing. No process had yet been able to make that water clear, and in large towns it was a very serious nuisance.

The PRESIDENT wished to ask the author whether the apparatus was still at work at Barclay's Brewery, where he believed it had been tried.

Mr. FARQUHAR said that machine was not now at work; but the apparatus tried there was not the same as that described in the paper. In fact it was a combination of the present machine with another of an entirely different character, to the detriment of the former. The combined machine was very unwieldy, covering about five times the space of the apparatus described in the paper.

The PRESIDENT said, with regard to Mr. Newman's question, it was stated at page 150, "River water having clay and slimy matters in suspension, such as choke up all ordinary filters, is filtered perfectly bright and continuously by the model machine;" so that the experiment had clearly been tried. Most of the experiments however seemed to have been tried with only a very small filter, $9\frac{7}{8}$ inches diameter.

Mr. FARQUHAR said in reply that it appeared incredible to Mr. Hawksley that they should deviate from the usual course of filtering slowly, and yet be able to obtain pure filtration. Yet the report of the chemist of the Fives-Lille Company, p. 149, stated that the filtration was as pure as that obtained from blotting-paper: which he believed was the test of pure filtration. The pressure used for that filtration was two atmospheres.

Mr. HAWKSLEY said that statement was to him the incredible part of the paper; and he had so described it in order to have the point cleared up.

Mr. FARQUHAR said Mr. Hawksley had compared the process with that of filtering through the ordinary sand beds; but there was a very great difference between the two. In filtering through coarse sand with this process, they had found that they could not use pressure, and could not get beyond a certain speed. They had also tried glass, powdered as finely as possible; and there they had arrested, on the surface, impurities that occurred in the water delivered from the mains of some of the water companies in London; they had actually taken off a coating deposited on the top of the glass surface. But finding that there was no satisfactory progress to be made in filtering rapidly through sand, they had tried sawdust, and then they found a very different state of affairs. The greater the pressure employed, the closer the grains of sawdust got pressed or knit together; and hence, as had been proved several times, by using sawdust as a medium they could get both speed and purity of filtration; which was not possible in a sand filter, because there the grains did not squeeze closer together under pressure. Judging the new process by the old one, of course it would appear incredible; and one required to see the process before believing it. They might however rest assured that there was no statement made in the paper which had not been verified; and the names had been given of those who had verified the facts. Even in the case of filtering such matter as the "eau-vanne," it would be seen on p. 149 that, with a depth of only 3 in., the liquid still passed out clear. There were several other cases which he might have mentioned; but he thought that was sufficient to show that the filtration was really pure. No doubt filtration through only 3 in. of sawdust would not purify water to the standard for drinking, and take out the small particles to which Mr. Hawksley had referred; but it would arrest any particles of lime or clay in suspension. The water might possibly show the appearance of a thin cloud, but no particles could be detected in it.

He quite agreed with Mr. Hawksley's remark that sawdust from pitch-pine or fir would not answer in its natural state for water filtration; but there were many simple and inexpensive ways of rendering this kind of sawdust inodorous, and therefore suitable as a filtering medium for potable water. The whole question as to the

best filtering material to be employed in each particular case had been under the consideration of an eminent chemist, and it was not improbable that many fibrous materials now looked upon as of little or no value would be made to render good service as filtering mediums. It was not at all necessary that sawdust only should be used. The paper had omitted to mention that if desired the filter-bed could be composed of two or more materials: the top portion being of such material as would mechanically arrest the solid impurities; while the lower portion was composed of any antiseptic material, such as charcoal &c., to purify the liquid chemically.

In reply to Mr. Newman's question as to whether they could arrest clay matter in suspension in the water, he might say it had been done several times, not only with sawdust but with the finely-powdered glass of which he had spoken. With sawdust, even in such a shallow depth as 3 in., it was possible to arrest any clay matter or lime in suspension, and the water would come out perfectly clear of them. As to any chemical action, such as Mr. Hawksley had alluded to as taking place in slow filtration, he could not speak to that; he spoke only of a mechanical filter, filtering by a bed of sawdust or some other material of the same kind—fibrous and soft, so that it could be squeezed like a sponge. As to Mr. Platt's question, the machine had not been employed for water used in coal-washing; but he thought there would be no difficulty in such employment, and should be happy to try any samples that might be furnished to him.

He wished to make one other remark. In the ordinary filtration at waterworks, he believed that they employed five or six feet depth of sand, shingle, and other materials, to obtain pure filtration; whereas in the machine described they would certainly not need a bed of more than a foot in depth to produce pure filtration. It would be easy to calculate what a saving that would produce with regard to the material employed.

Mr. Hawksley asked leave to point out that the shingle and other materials under the sand had nothing whatever to do with the filtration; they only gave support to the sand, and allowed vacuities for the water coming from the sand to escape into.

The PRESIDENT proposed a vote of thanks to the author for his paper, which was passed unanimously.

General View of Mowing Machine.

(See Fig. 1, Plate 1.C.)

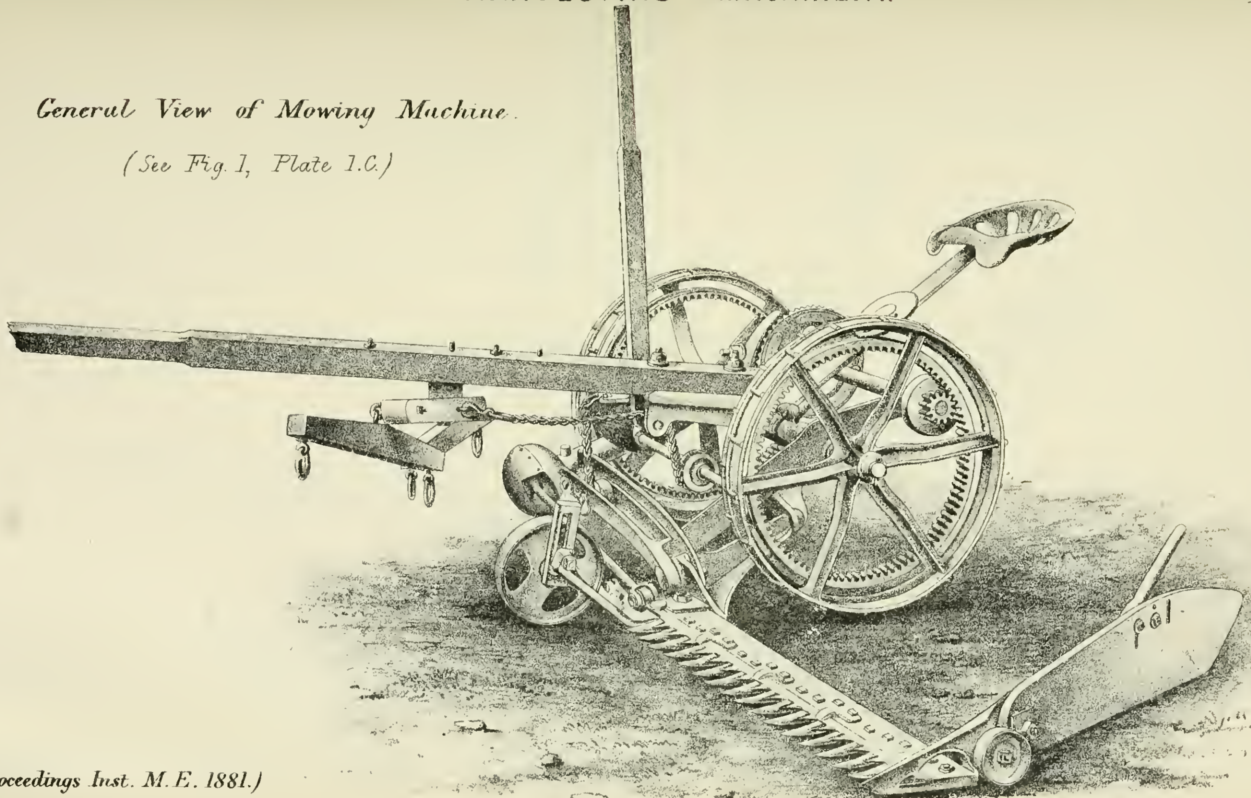


Plate 1A.

General View of Automatic Side-delivery Reaper.

(See Plates 7 and 8)

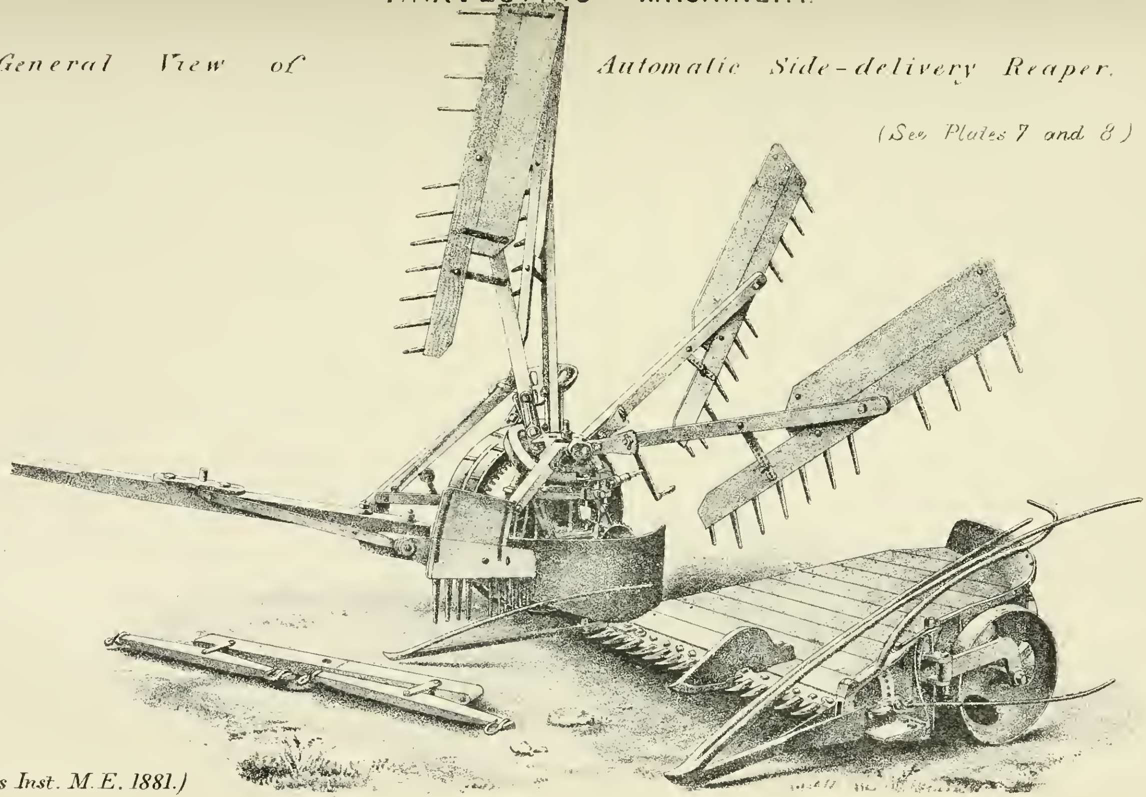


Plate 1.B.

Fig. 1. *Mower driven from Wheels direct.*

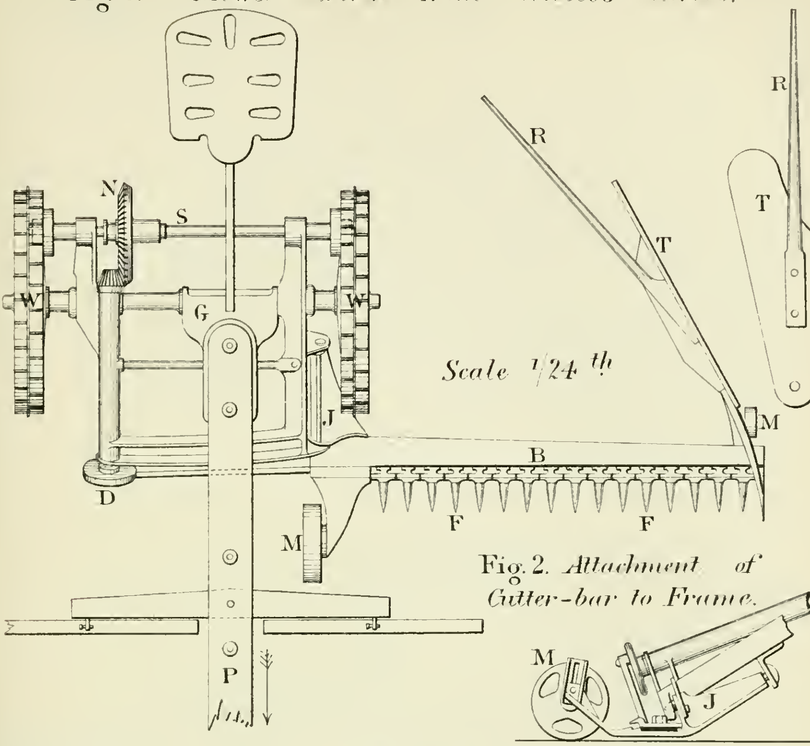


Fig. 2. *Attachment of Cutter-bar to Frame.*

Fig. 4. *Fingers, Samuelson's Open Pattern.*

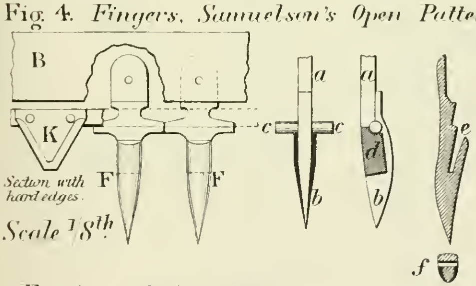


Fig. 3. *Mower driven from main Axle.*

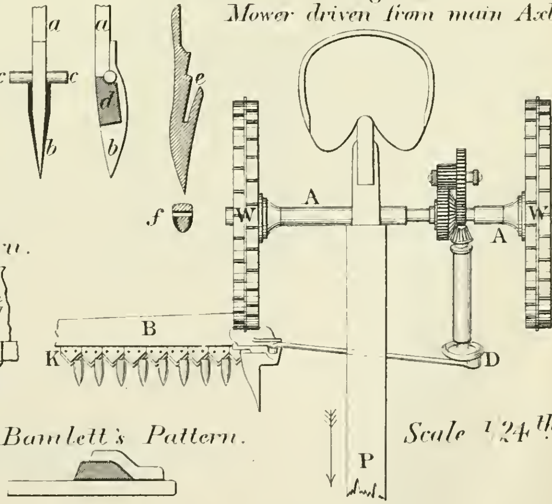


Fig. 5. *Solid Pattern.*

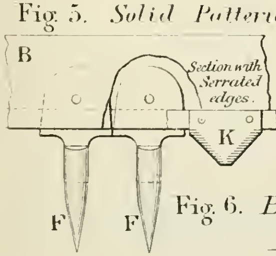


Fig. 6. *Bamlett's Pattern.*

Combined Mower and Reaper.

Fig. 7. Elevation. *Scale 1/16th*

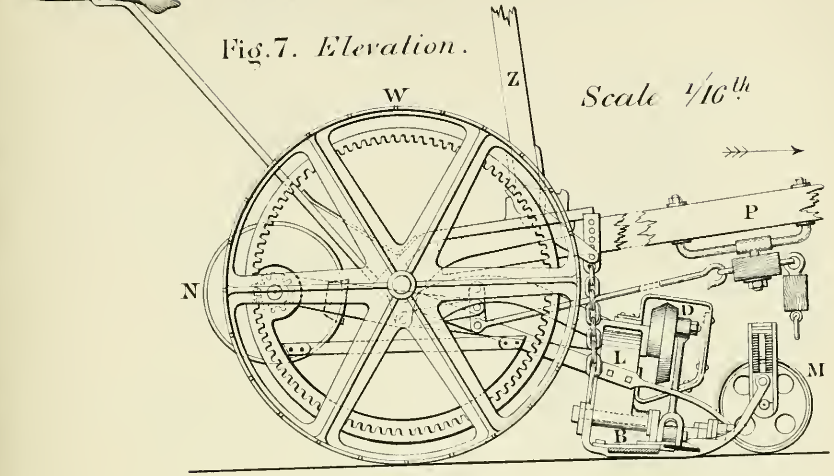
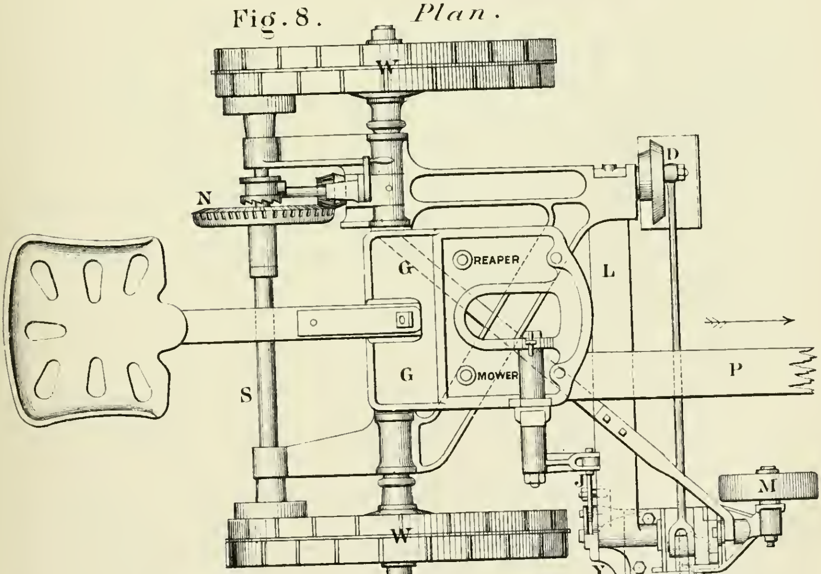


Fig. 8. Plan.



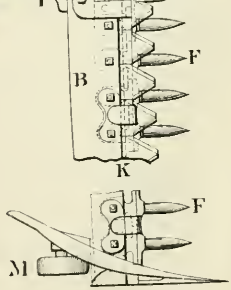
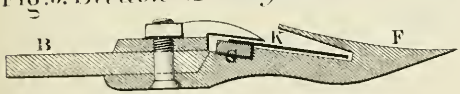


Fig. 9. Section of Finger-bar and Knife.



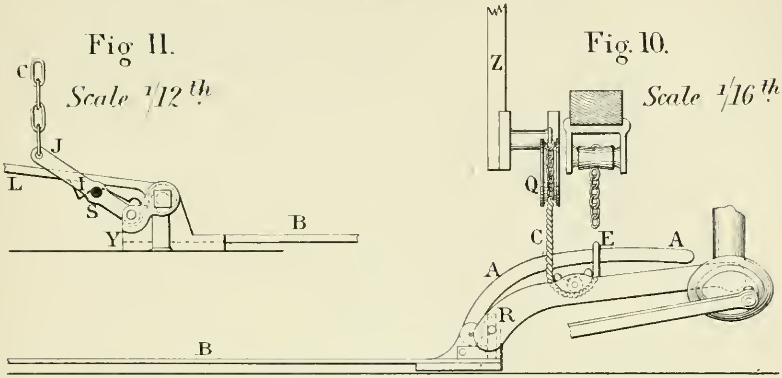
Scale 1/4th

(Proceedings Inst. M. E. 1881).

Gear for Parallel Lift.

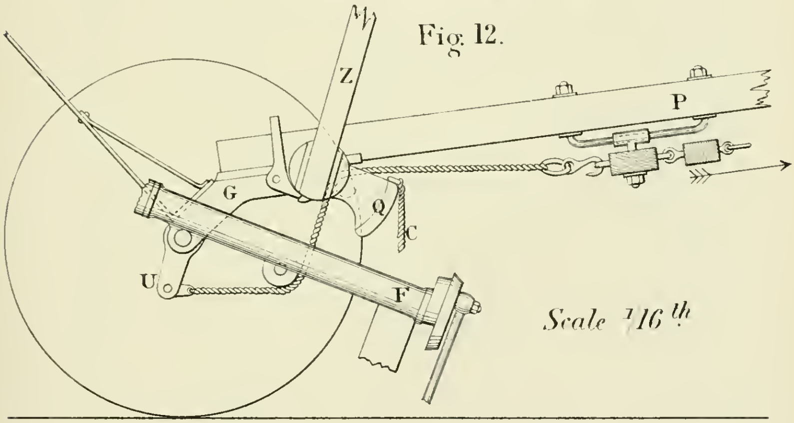
Fig 11. *Scale 1/12th.*

Fig. 10. *Scale 1/16th.*



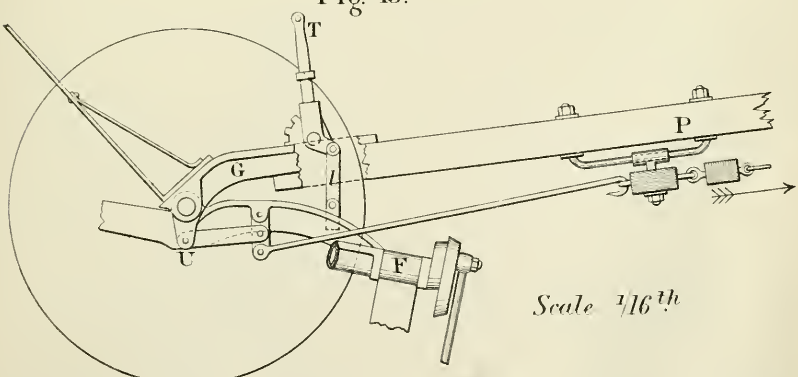
Gear for balancing downward action.

Fig. 12.



Scale 1/16th.

Fig. 13.



Scale 1/16th.

Ins. 12 9 6 3 0 1 2 3 4 *Feet.*

HARVESTING MACHINERY.

Reaping Machines.

Fig. 14. *Off-side Shoe.*

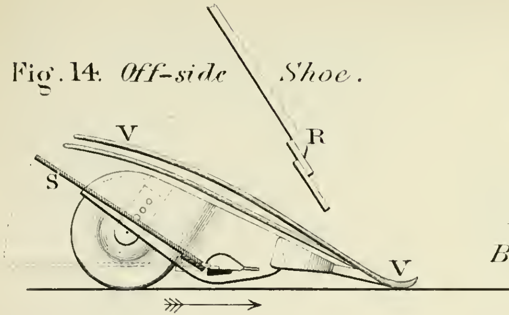


Fig. 15. *Swivel Attachment for Off-side Shoe.*

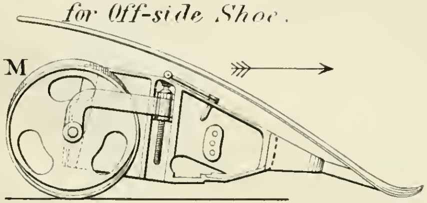


Fig. 16. *Automatic Back-delivery Reaper.*

Scale 1/24th.

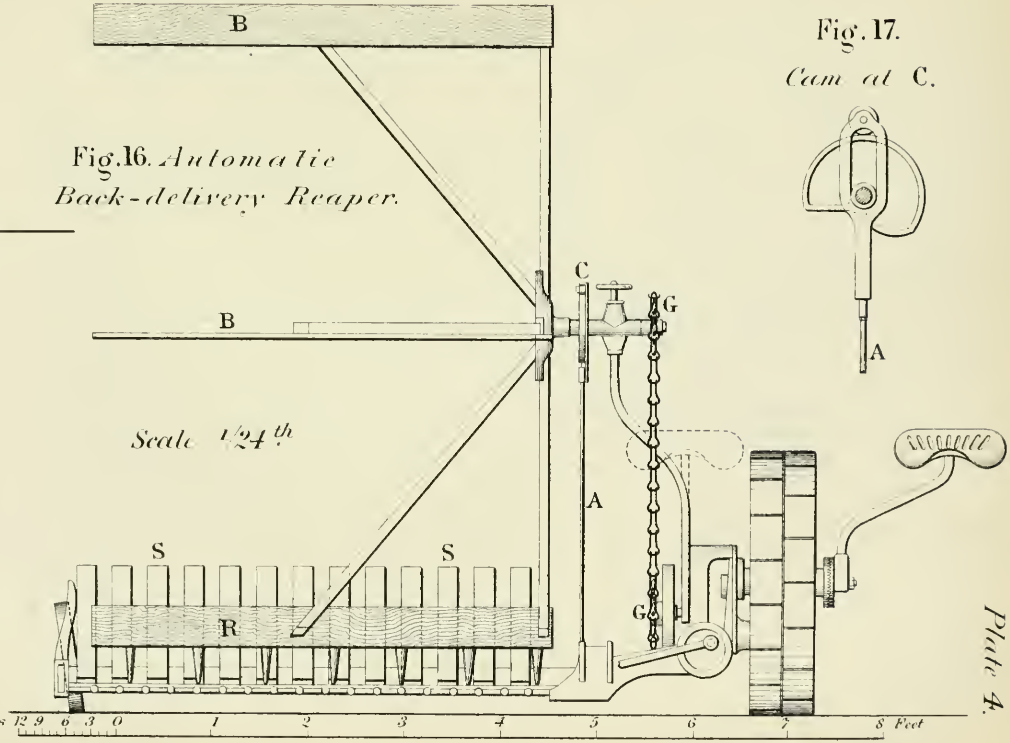
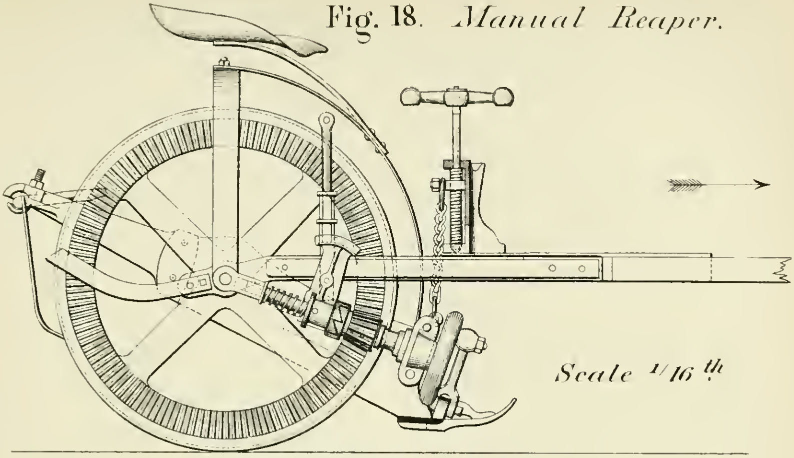


Fig. 17. *Cam at C.*

(*Proceedings Inst. M. E. 1881*).

Fig. 18. *Manual Reaper.*



Automatic Side-delivery Reapers.

Fig. 19. *Upright Rake-shaft.*

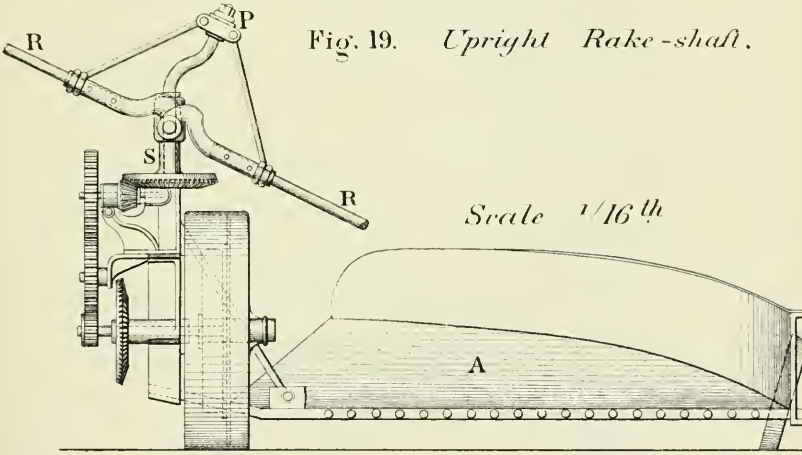
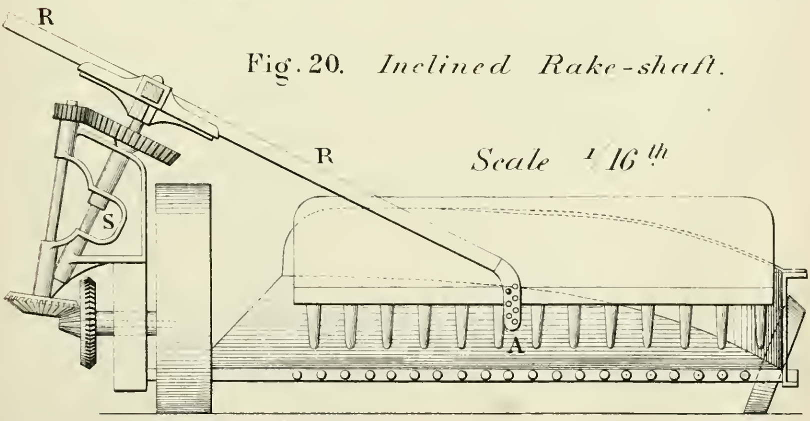


Fig. 20. *Inclined Rake-shaft.*



Manual Back-delivery Reaper.

Fig. 21. *Elevation.*

Scale 1/12th.

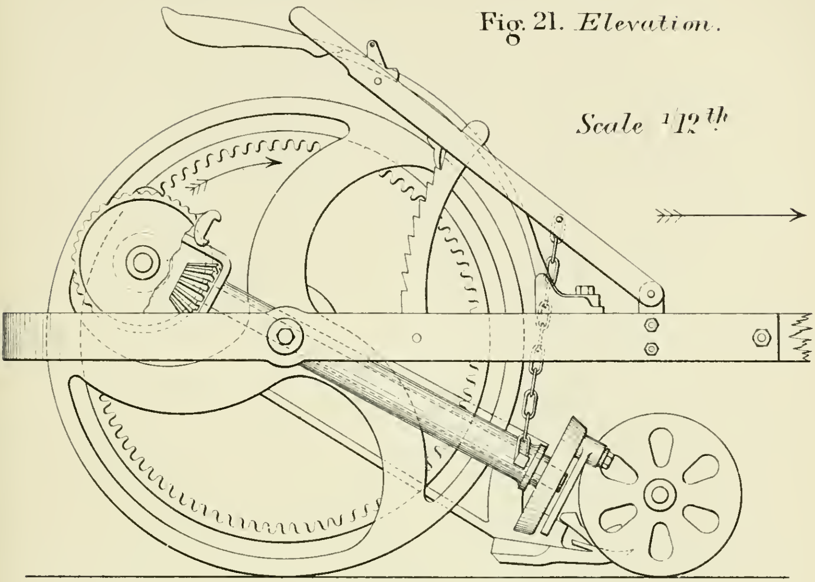


Fig. 23. *Clutch Pinion at* P.
Scale 1/4th.

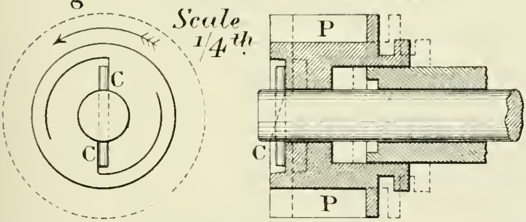
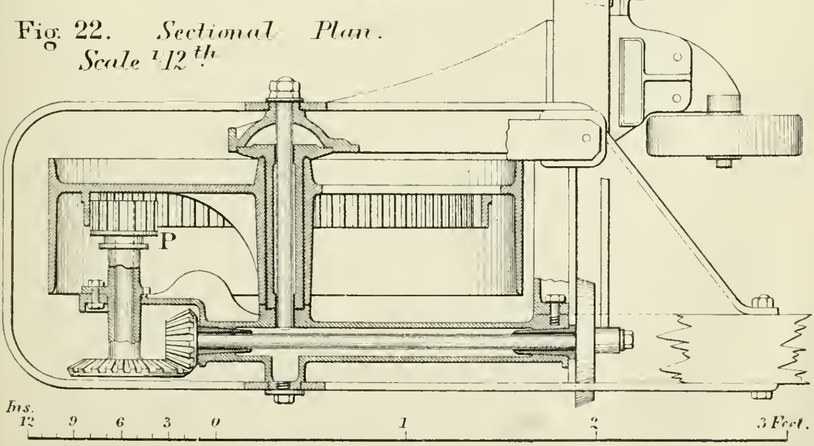


Fig. 22. *Sectional Plan.*
Scale 1/12th.



Automatic Side-delivery Reaper with Cam-Path for Rakes.

Fig. 24. *Elevation.*

Scale 1/12th.

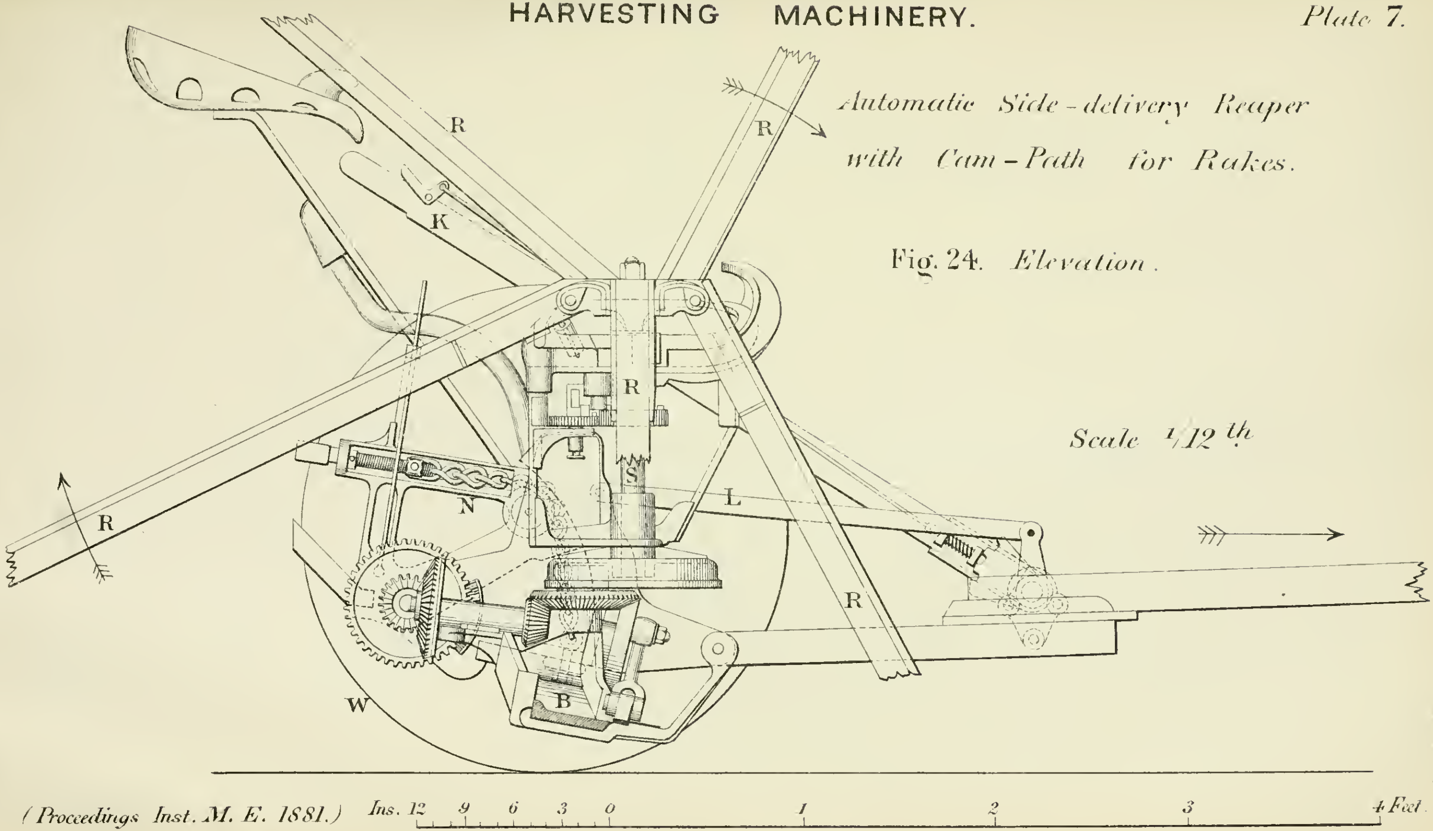


Plate 7.

HARVESTING MACHINERY.

Automatic Side-delivery Reaper, with Cam-Path for Rakes.

Fig. 25. *Plan.*

Scale 1/16th

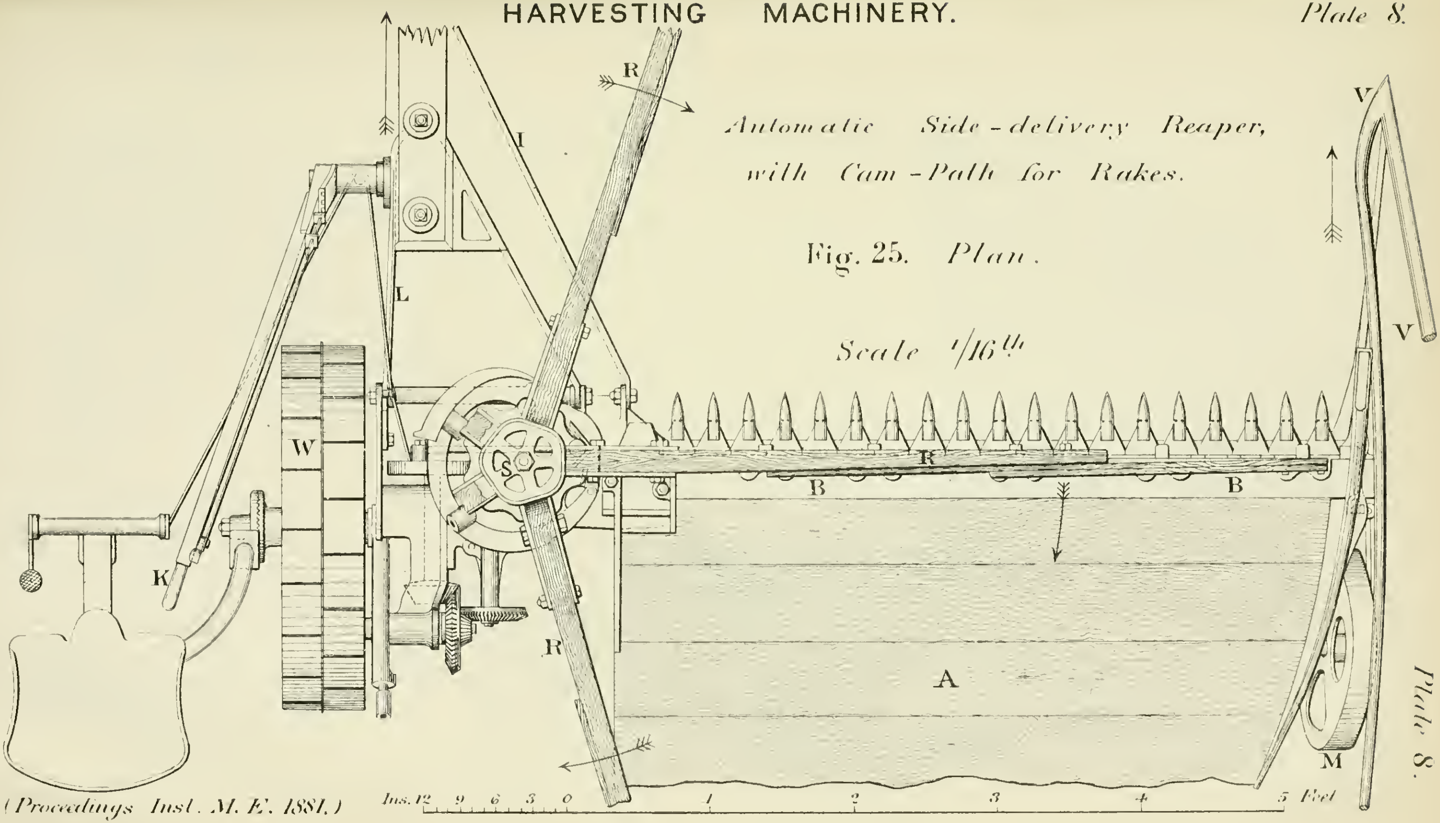
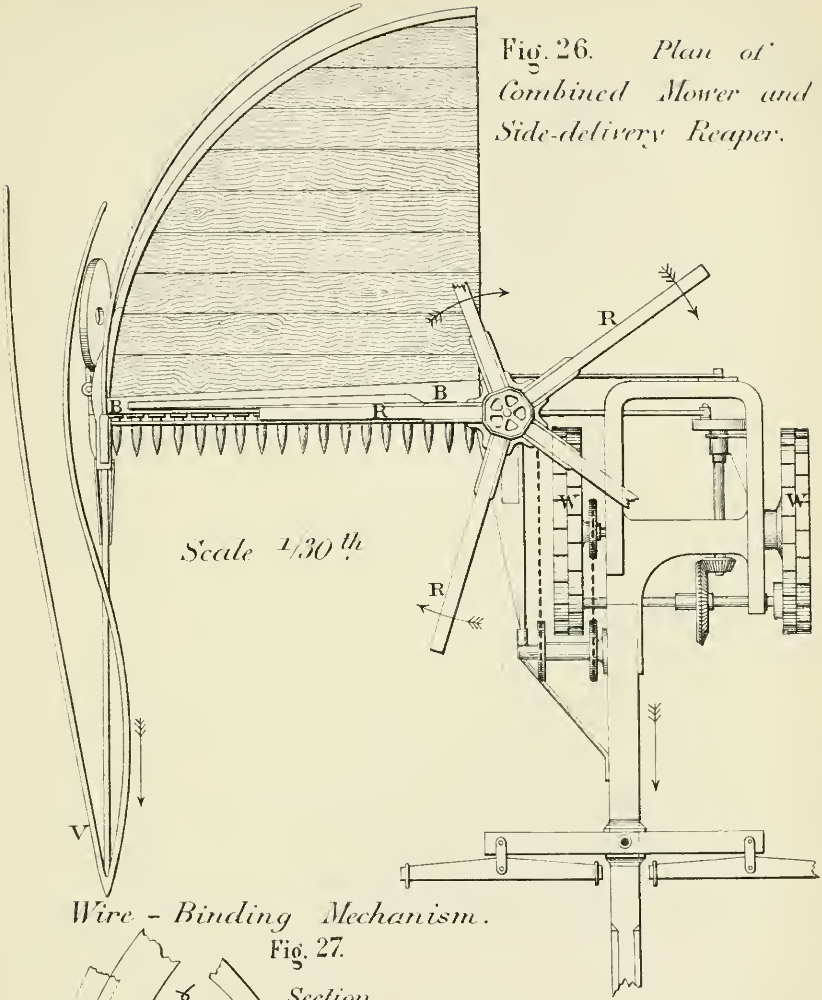


Plate 8.

Fig. 26. *Plan of Combined Mower and Side-delivery Reaper.*



Scale 1/30th.

Wire - Binding Mechanism.

Fig. 27.

Section.

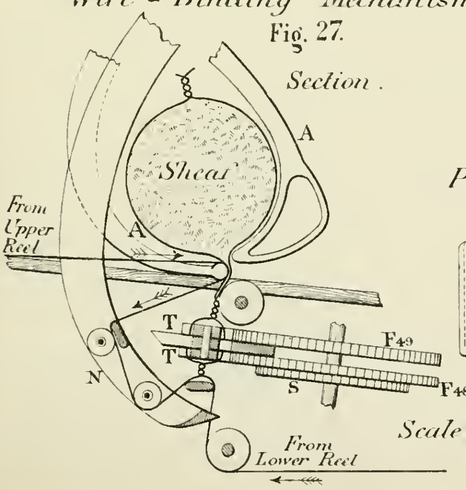
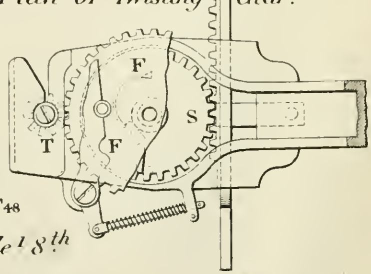


Fig. 28.

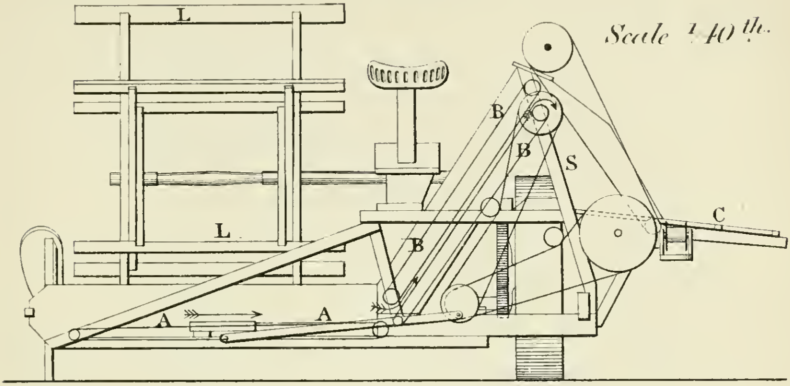
Plan of Twisting Gear.



Scale 1/8th.

(Proceedings Inst. M. E. 1881.)

Fig. 29. *Wire-Binder, Ordinary Arrangement.*



Scale 1/40th.

Samuelson's Wire-Binder.

Fig. 30. *General Arrangement at commencement.*

Scale 1/40th.

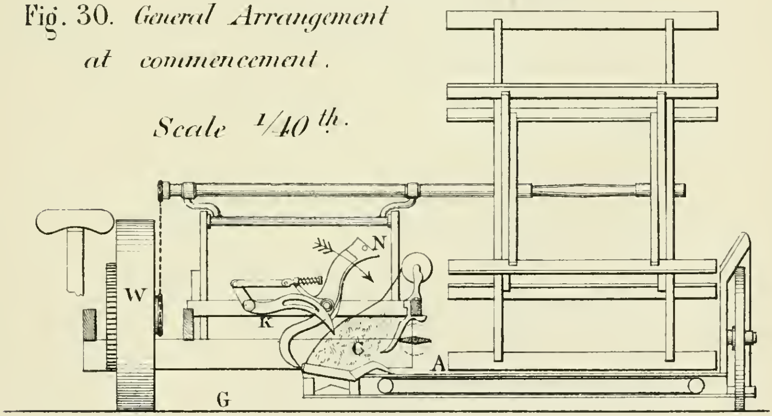
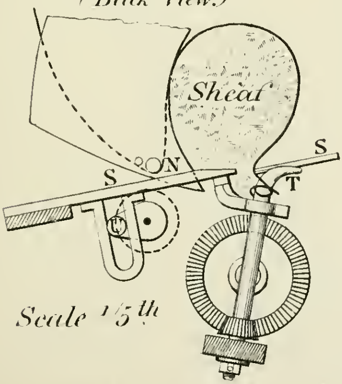
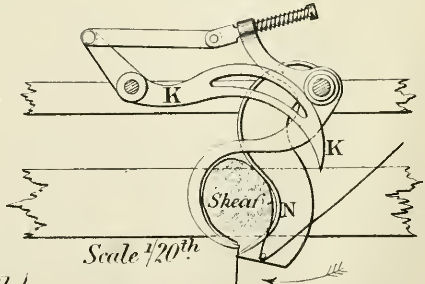


Fig. 31. *Twisting Gear.* *(Back View.)*



Scale 1/5th.

Fig. 32. *Arrangement during Twisting.* *(Front View.)*



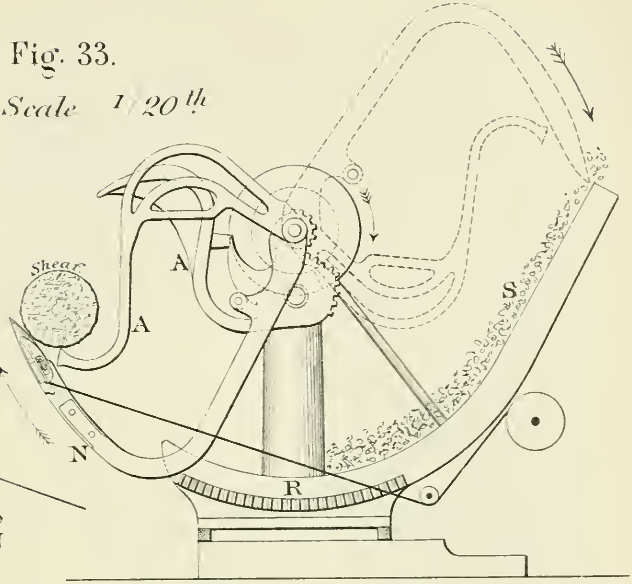
Scale 1/20th.

(Proceedings Inst. M. E. 1881.)

Wire - binders.

Fig. 33.

Scale 1/20th



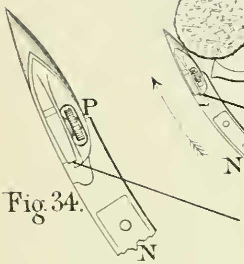
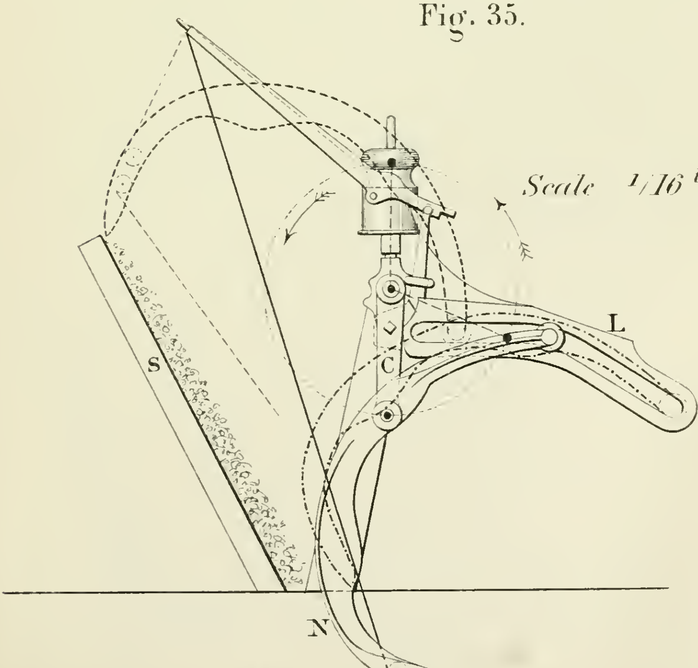


Fig. 34.

Fig. 35.

Scale 1/16th



Mc Cormick's Wire-Binding Apparatus.

Fig. 36. *Position at commencement.*
(Front View)

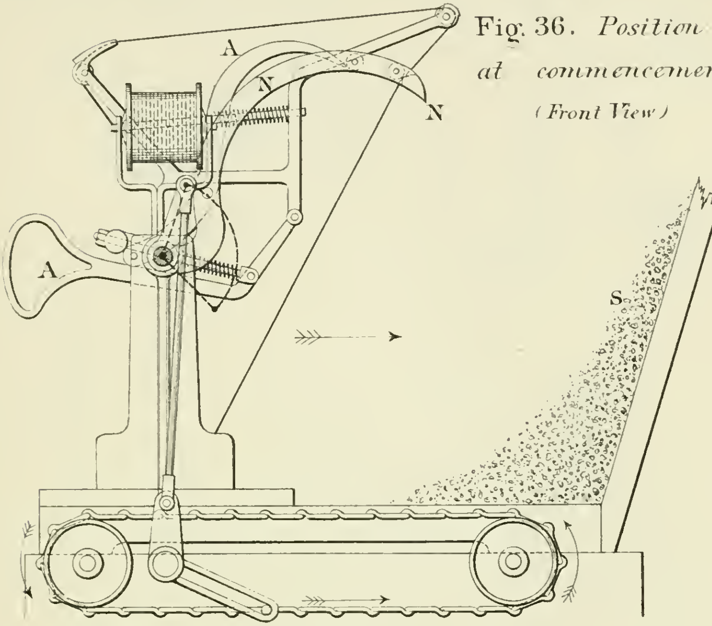
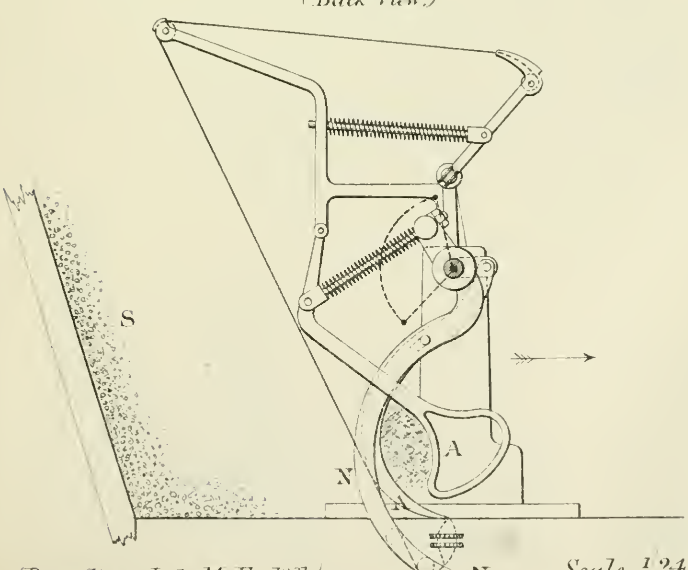


Fig. 37. *Position before Kicking off.*
(Back View.)



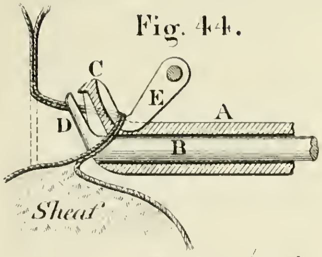
Scale 1/24th

Ins. 12 9 6 3 0 1 2 3 4 5 6 Feet.

HARVESTING MACHINERY.

Samuelson's String-binder.

Fig. 44.



Scale 1/3 rd

Fig. 45.

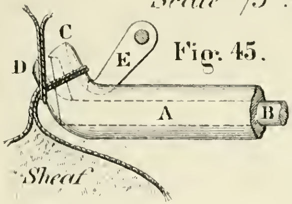
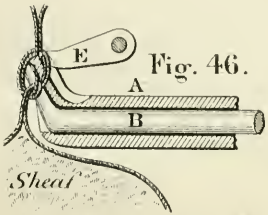


Fig. 46.

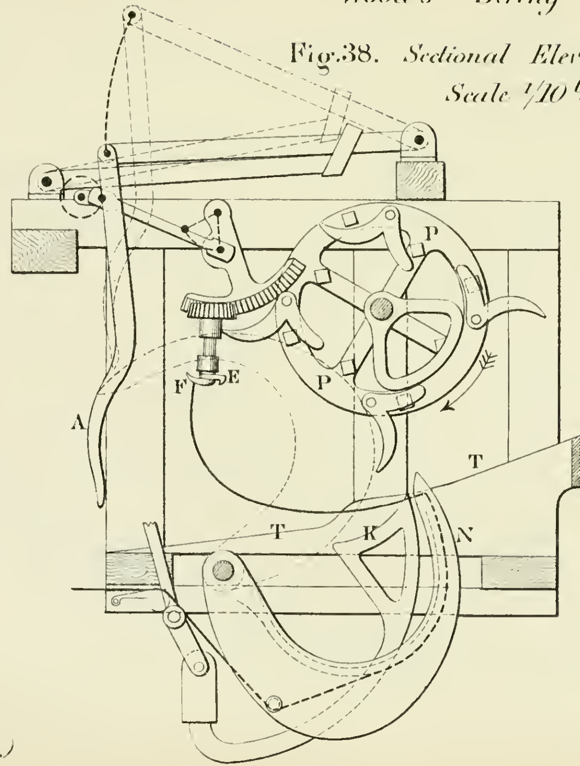


(Proceedings Inst. M. E. 1881.)

Wood's String-binder.

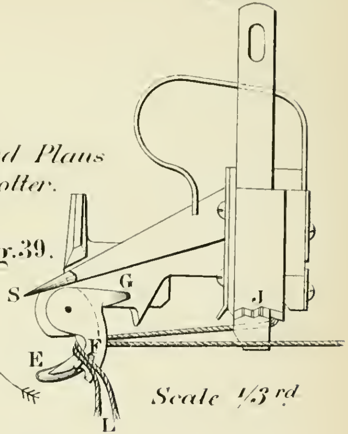
Fig. 38. Sectional Elevation.

Scale 1/10 th



Inverted Plans of Knotter.

Fig. 39.



Scale 1/3 rd

Fig. 40.

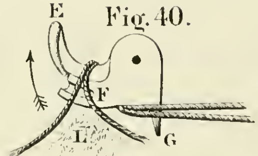
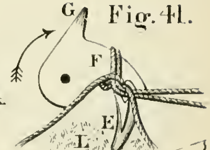


Fig. 41.



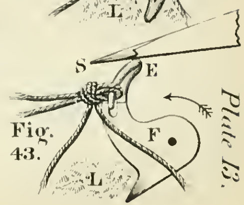


Fig. 42.

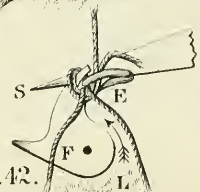


Fig. 43.

MACHINES FOR COLD AIR.

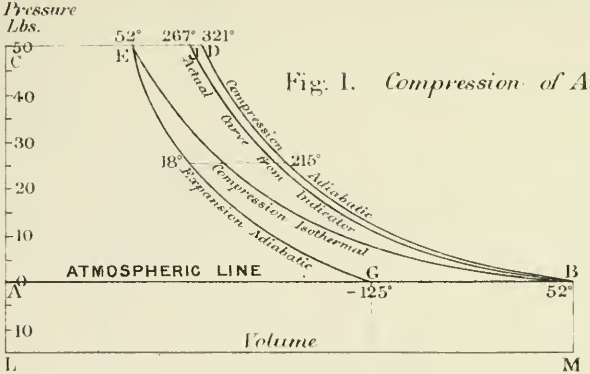


Fig. 1. *Compression of Air.*

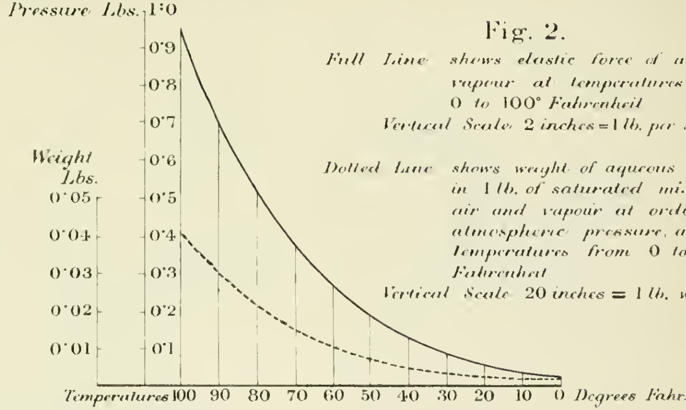


Fig. 2.

Full Line shows elastic force of aqueous vapour at temperatures from 0 to 100° Fahrenheit

Vertical Scale 2 inches = 1 lb. per sq inch.

Dotted Line shows weight of aqueous vapour in 1 lb. of saturated mixture of air and vapour at ordinary atmospheric pressure, and at temperatures from 0 to 100° Fahrenheit

Vertical Scale 20 inches = 1 lb. weight.

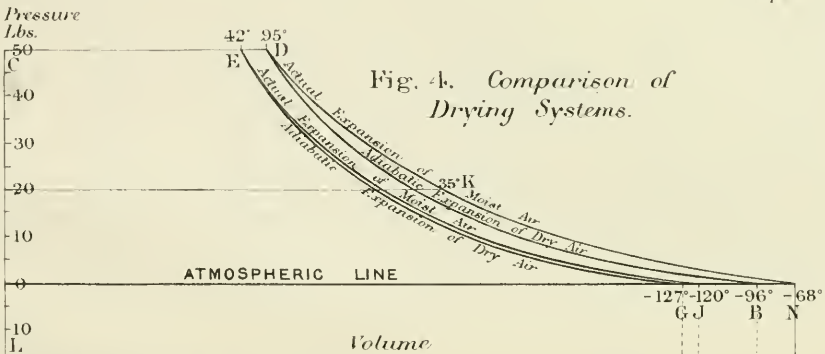


Fig. 4. *Comparison of Drying Systems.*

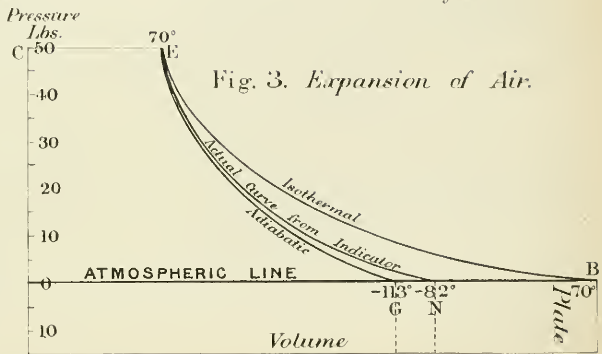


Fig. 3. *Expansion of Air.*

Vertical Scale 1 inch = 40 Lbs.

MACHINES FOR COLD AIR.

Hall's Machine, First Design.

Fig. 5. End Elevation.

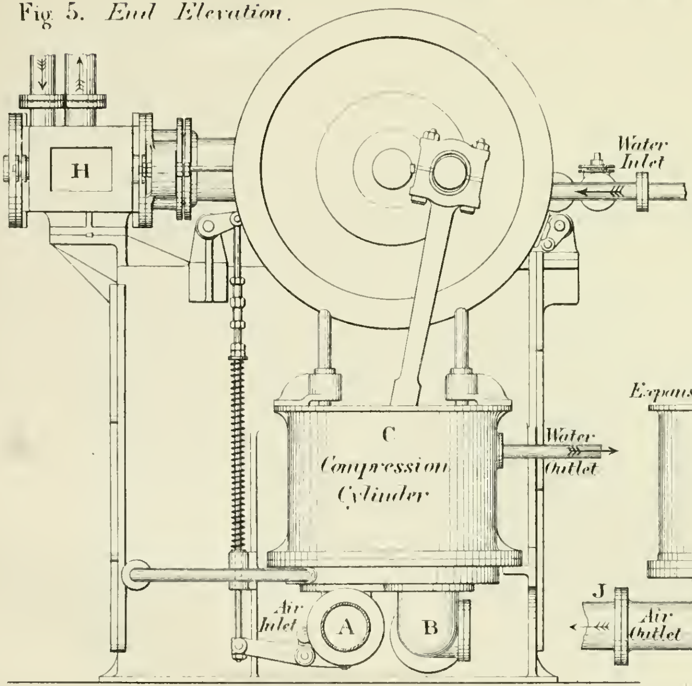
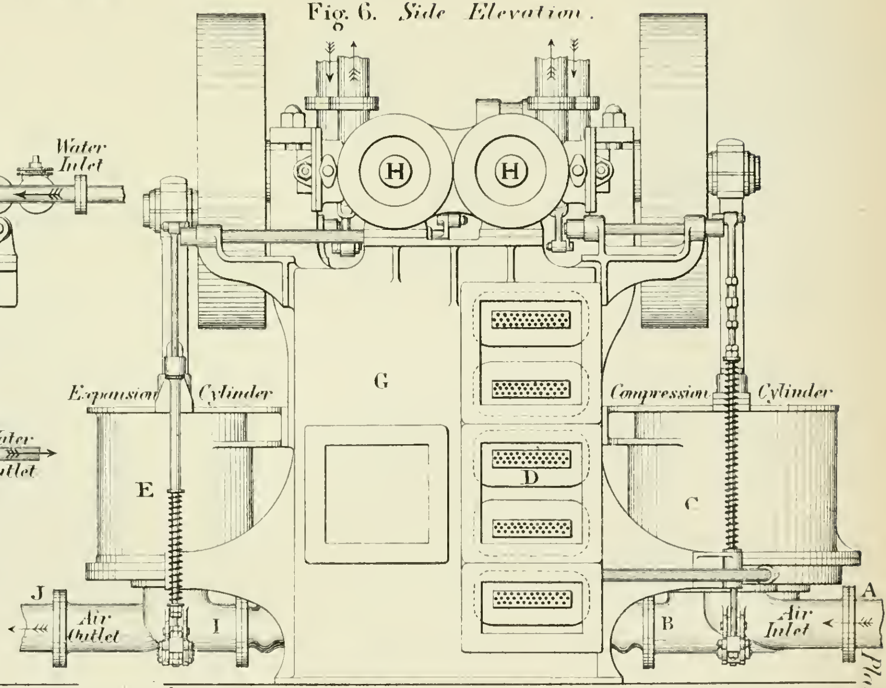


Fig. 6. Side Elevation.



Scale 1/30th

Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet.

(Proceedings Inst. M. E. 1881.)

Plate 15.

Fig. 7. *Cooler.*

Scale 1/24th.

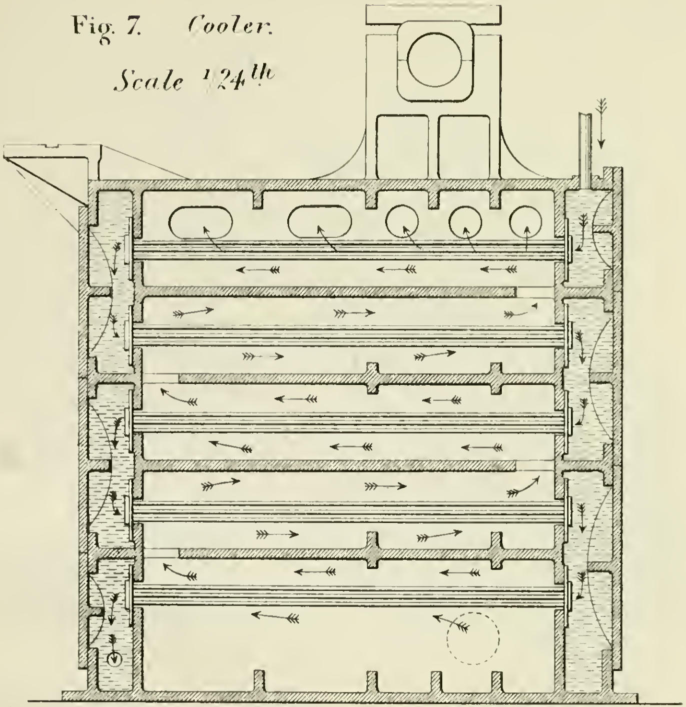
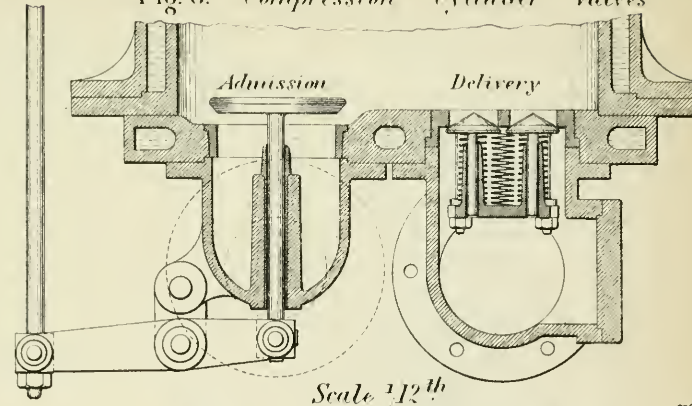


Fig. 8. *Compression Cylinder Valves*



Scale 1/12th.

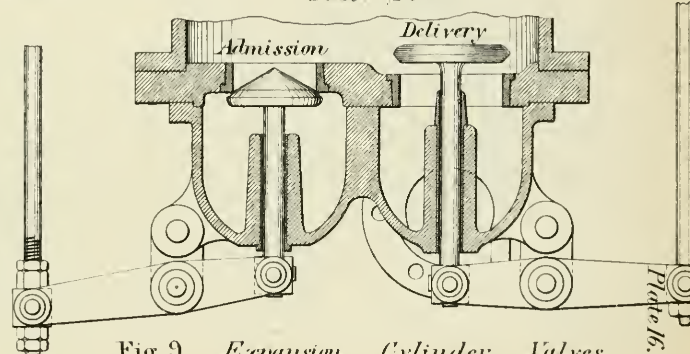


Fig. 9. *Expansion Cylinder Valves.*

(Proceedings Inst. M. E. 1881.)

Plate 16.

MACHINES FOR COLD AIR.

Hall's Machine, smaller size.

Fig 10. *Side Elevation.*

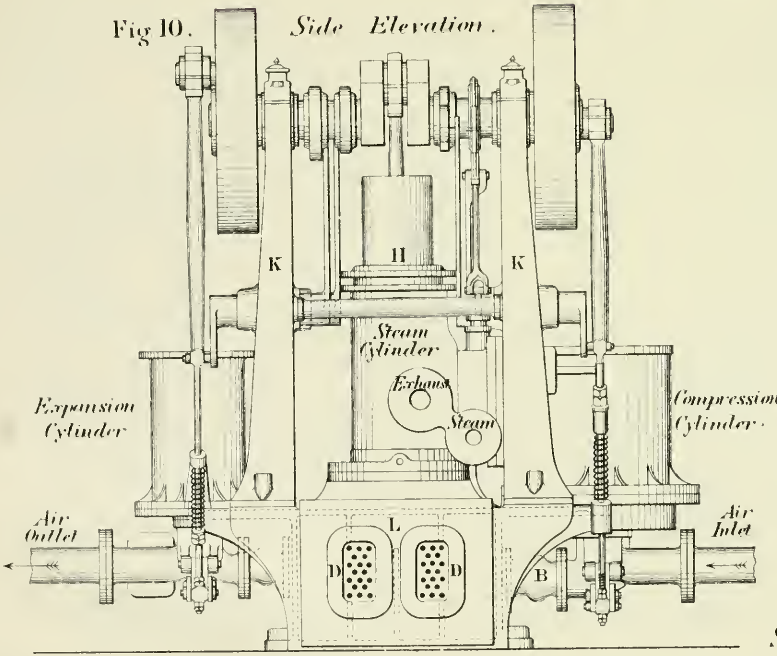
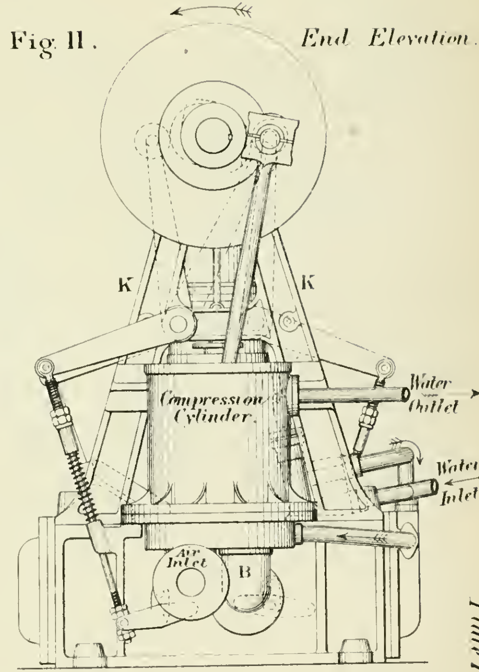


Fig 11. *End Elevation.*



Scale 1/20th

Ins 12 9 6 3 0 1 2 3 4 5 6 Feet.

(*Proceedings Inst M. E. 1881.*)

Plate 17.

MACHINES FOR COLD AIR.

Hall's Machine, with Double Expansion.

Fig. 12.
End Elevation

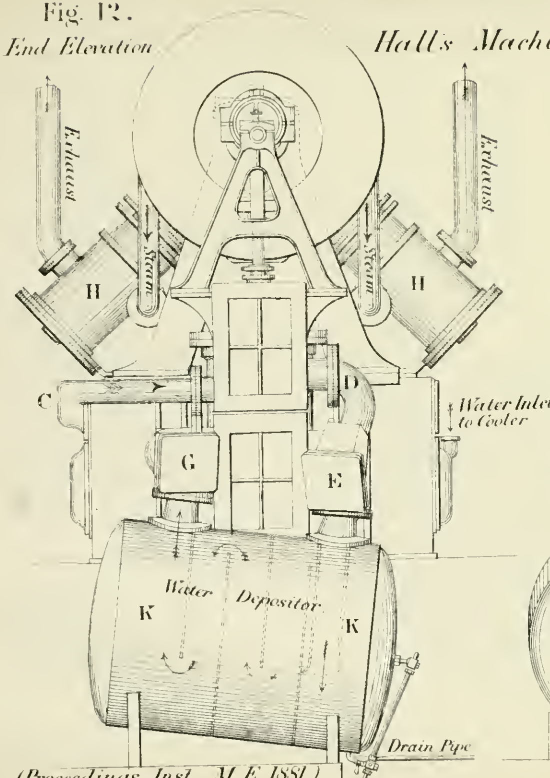


Fig. 13.
Side Elevation.

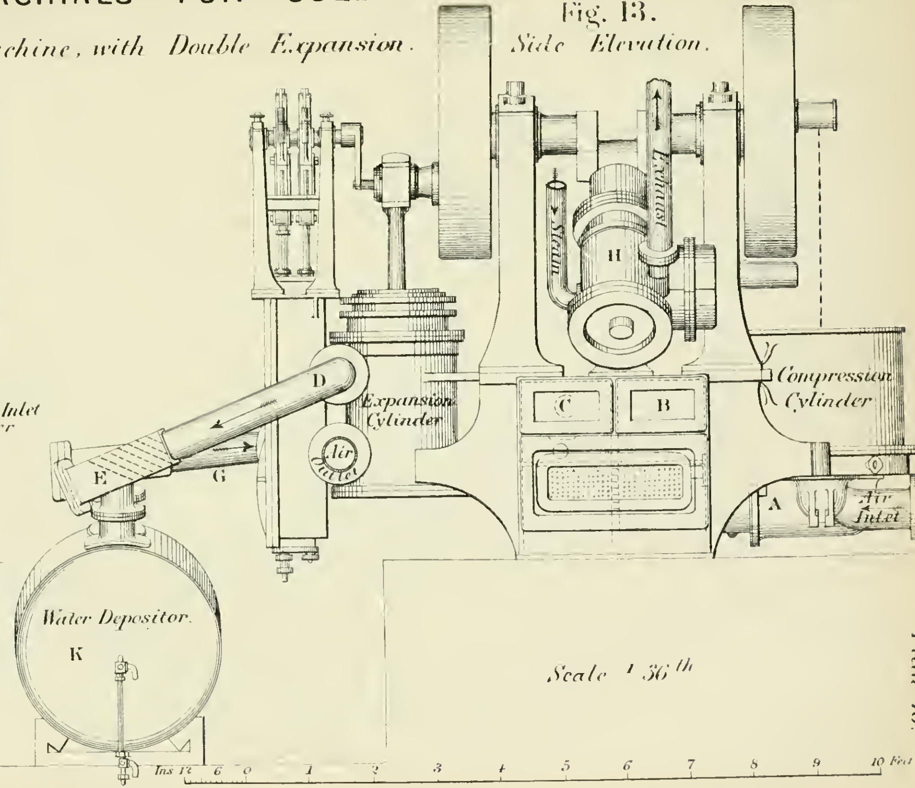
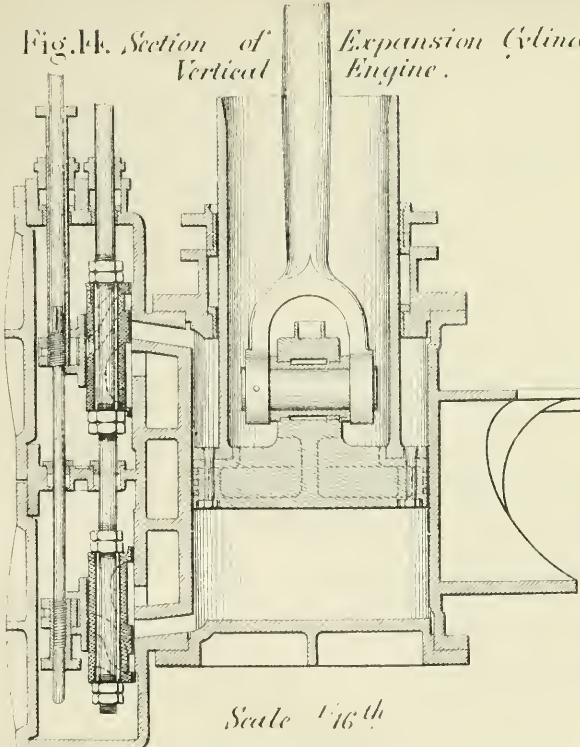


Plate 18.

(Proceedings Inst. M.E. 1881.)

MACHINES FOR COLD AIR.

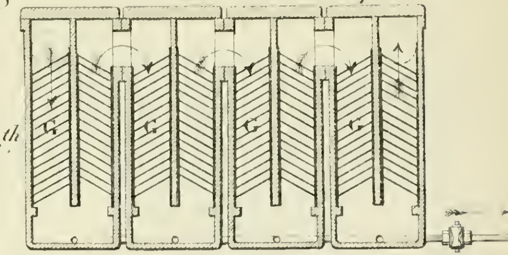
Fig. 14. Section of Expansion Cylinder, Vertical Engine.



Scale 1/16th.

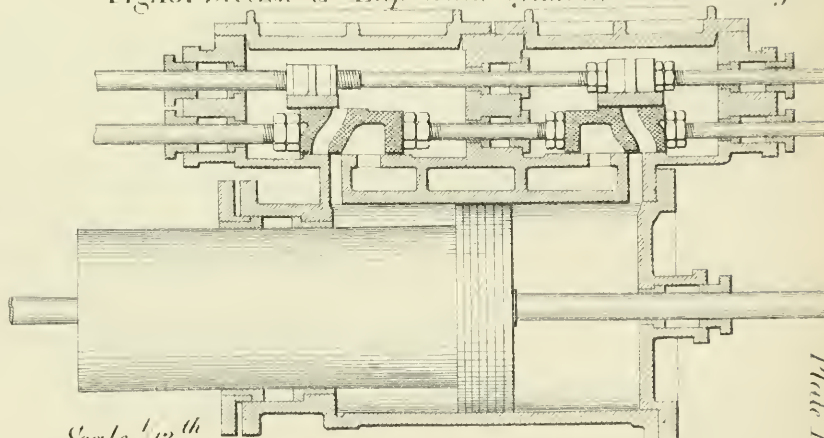
(Proceedings Inst. M. E. 1881.)

Fig. 15. Section of Water Depositor.



Scale 1/24th.

Fig. 16. Section of Expansion Cylinder: Horizontal Engine.

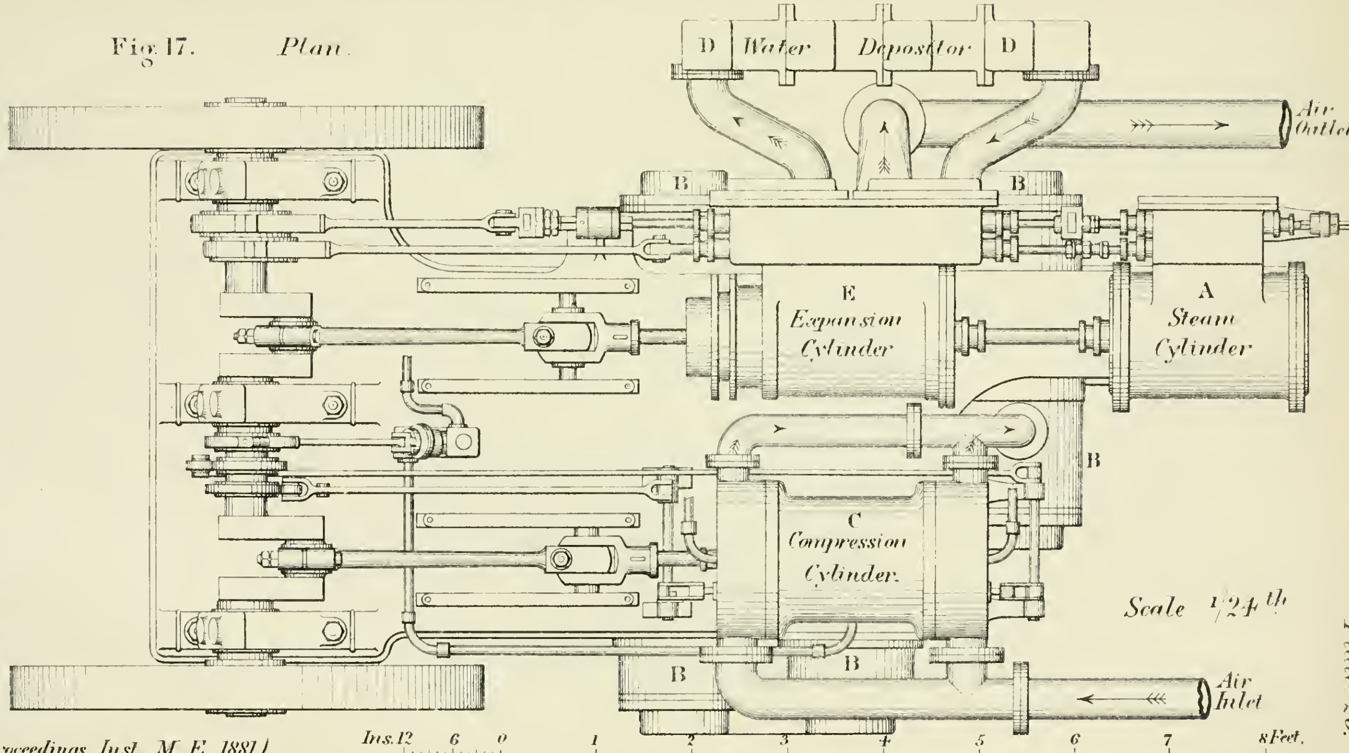


Scale 1/12th.

MACHINES FOR COLD AIR.

Horizontal Machine, with double expansion.

Fig. 17. *Plan.*



(Proceedings Inst. M. E. 1881.)

Plate 20.

Air-diagrams from Moist-air Machine.

Fig. 18. *Compression Cylinder.*

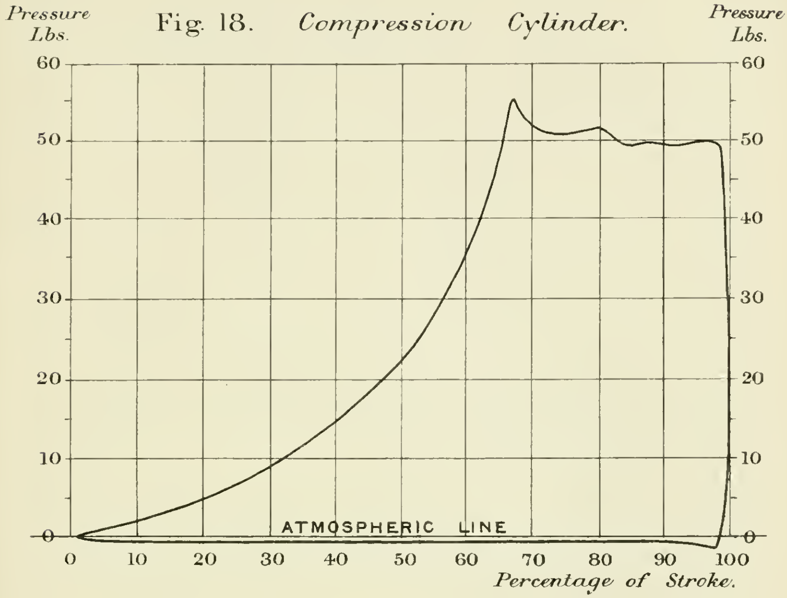
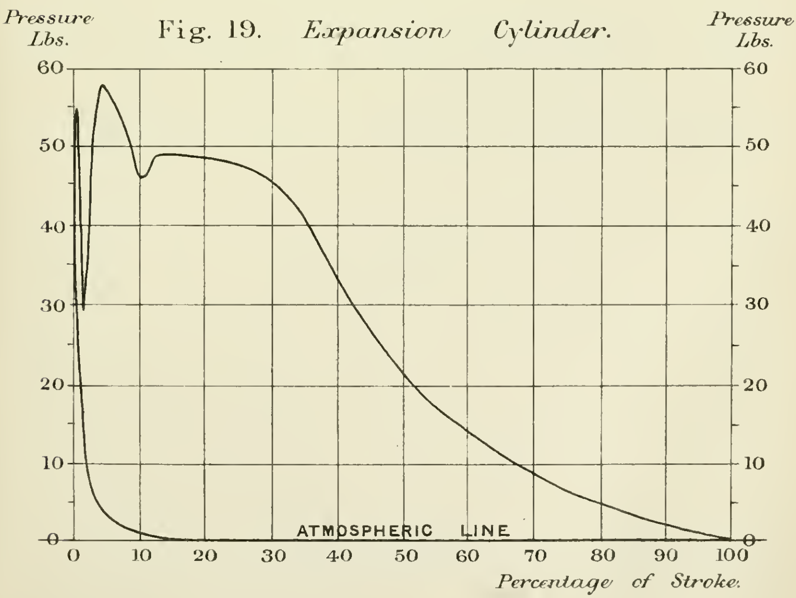


Fig. 19. *Expansion Cylinder.*



(Proceedings Inst. M.E. 1881.)

Air-diagrams from Vertical Dry-air Machine.

Fig. 20. *Compression Cylinder.*

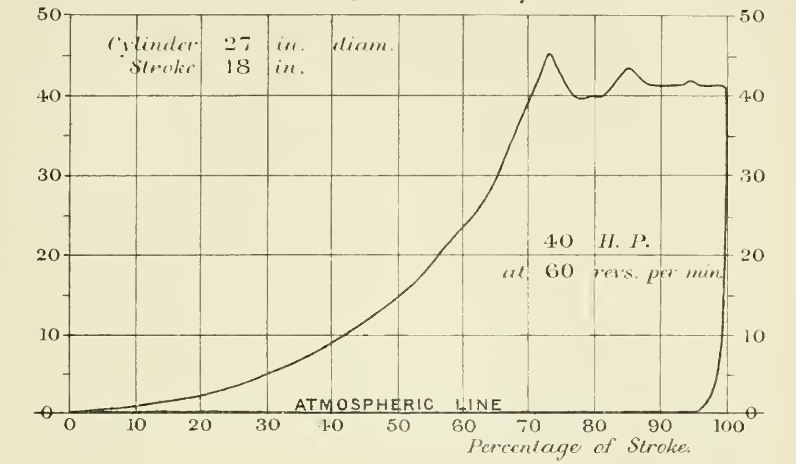


Fig. 21. *First Expansion in annulus.*

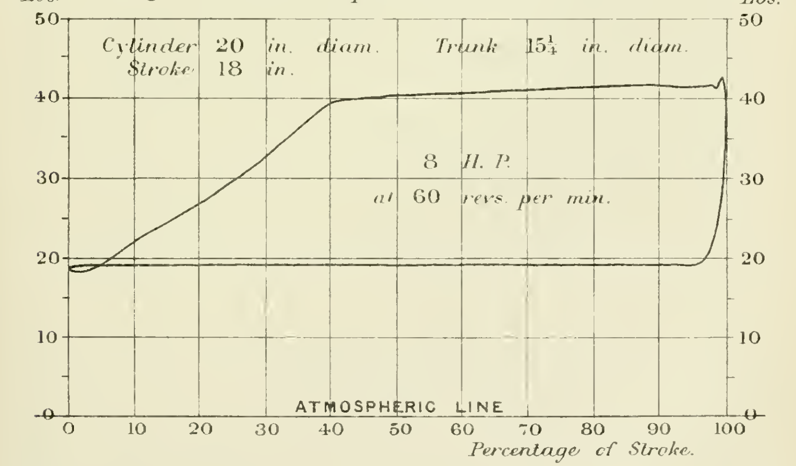
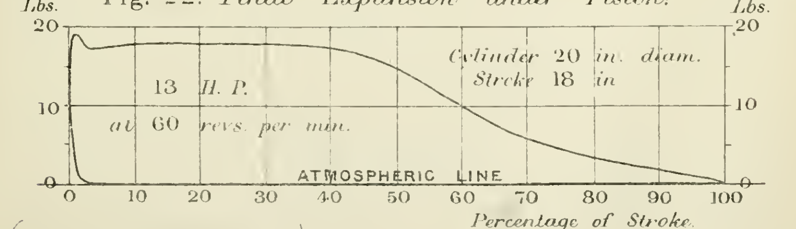


Fig. 22. *Final Expansion under Piston.*



(*Proceedings Inst. M.E. 1881.*)

Air diagrams from Vertical Dry air Machine.

Fig. 23. *Compression Cylinder.*

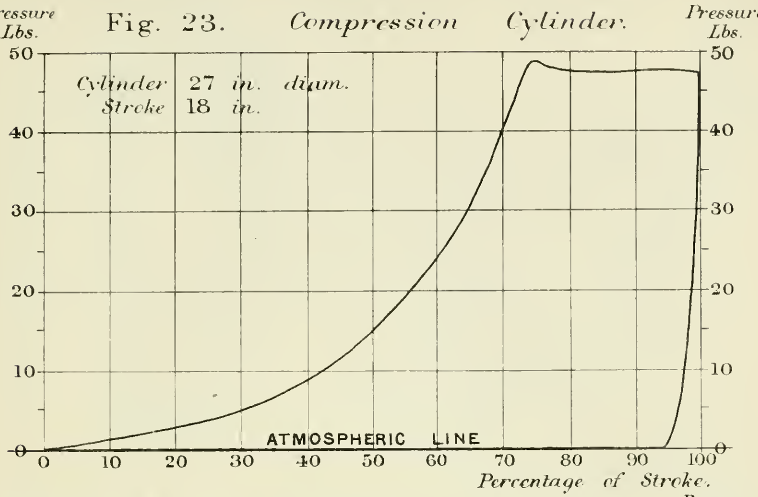


Fig. 24. *First Expansion in annulus.*

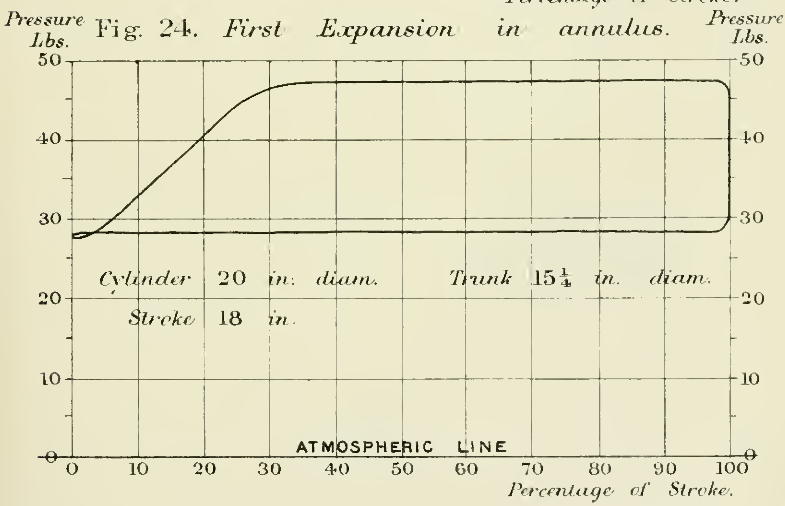
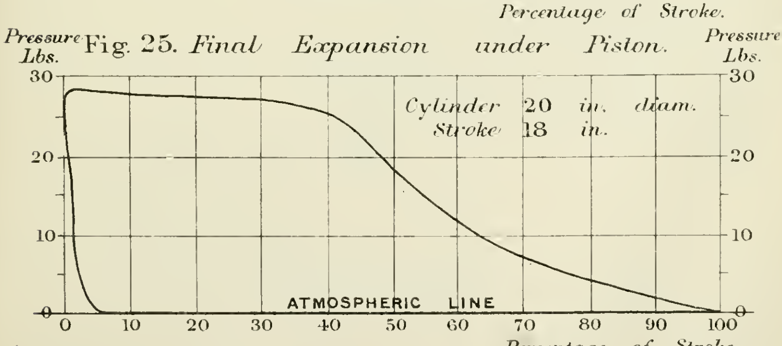


Fig. 25. *Final Expansion under Piston.*



(Proceedings Inst. M. E. 1881.)

STONE-DRESSING MACHINERY. *Plate 24.*

Fig. 1. *Section of Chuck.*

Scale 1/8th.

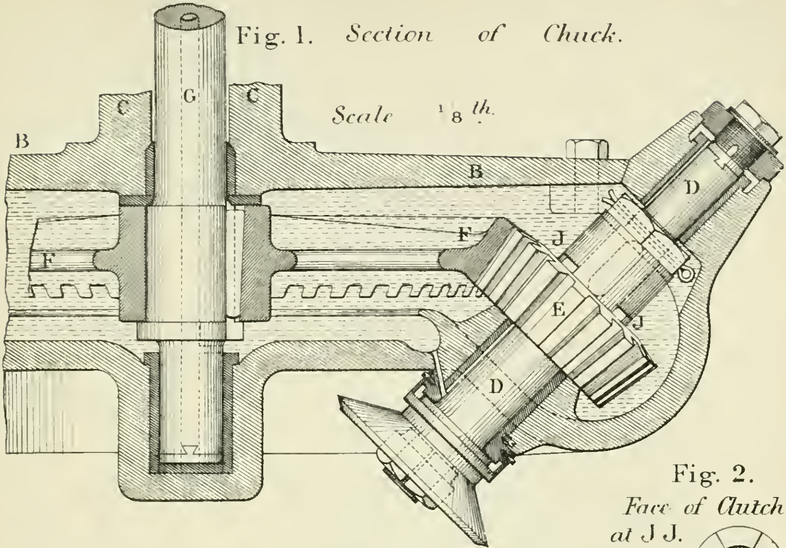


Fig. 2.
Face of Clutch at J J.

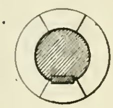
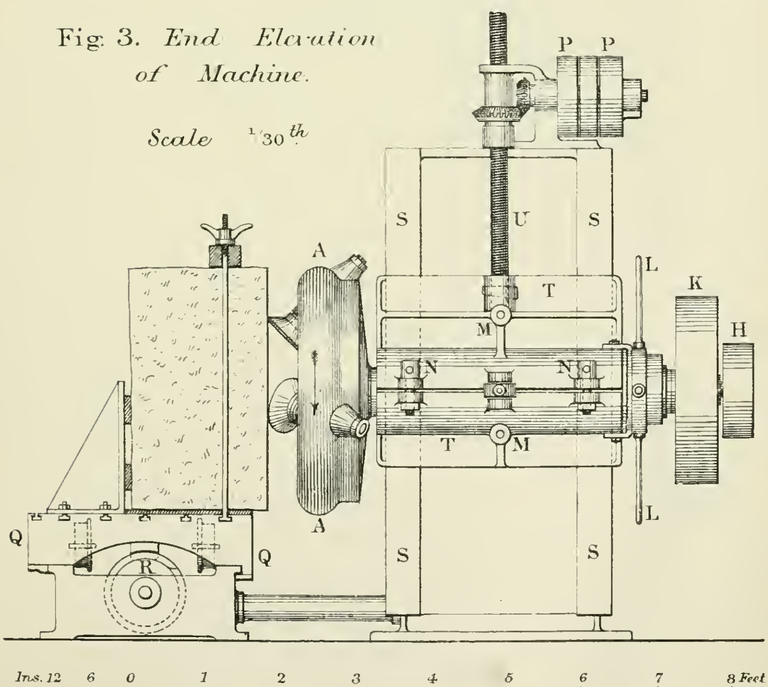


Fig. 3. *End Elevation of Machine.*

Scale 1/30th.



Scale 1/30th.

STONE-DRESSING MACHINERY.

Fig. 6.
Diagram of Motions.

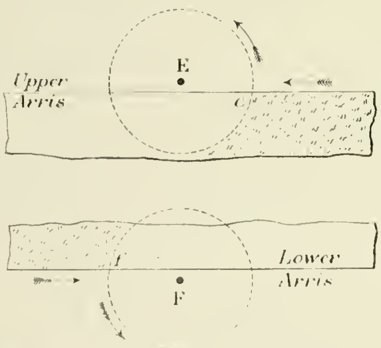
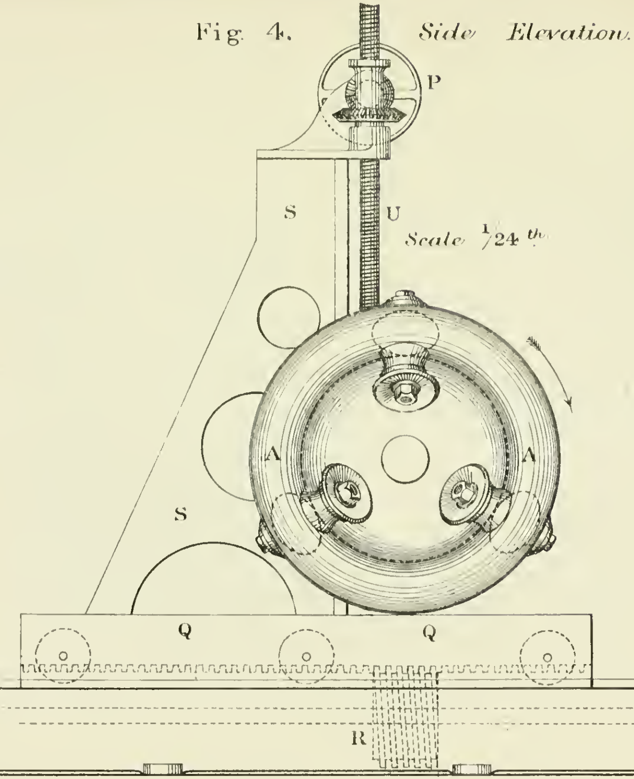
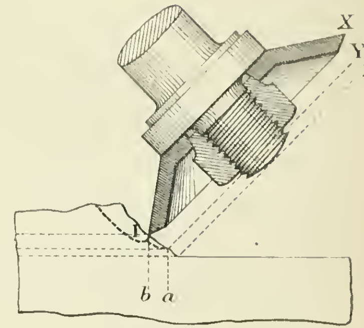


Fig. 4. *Side Elevation.*



Scale 1/24 th.

Fig. 5. *Action of Cutters.*



Scale 1/6 th.

Plate 25.

FARQUHAR FILTER.

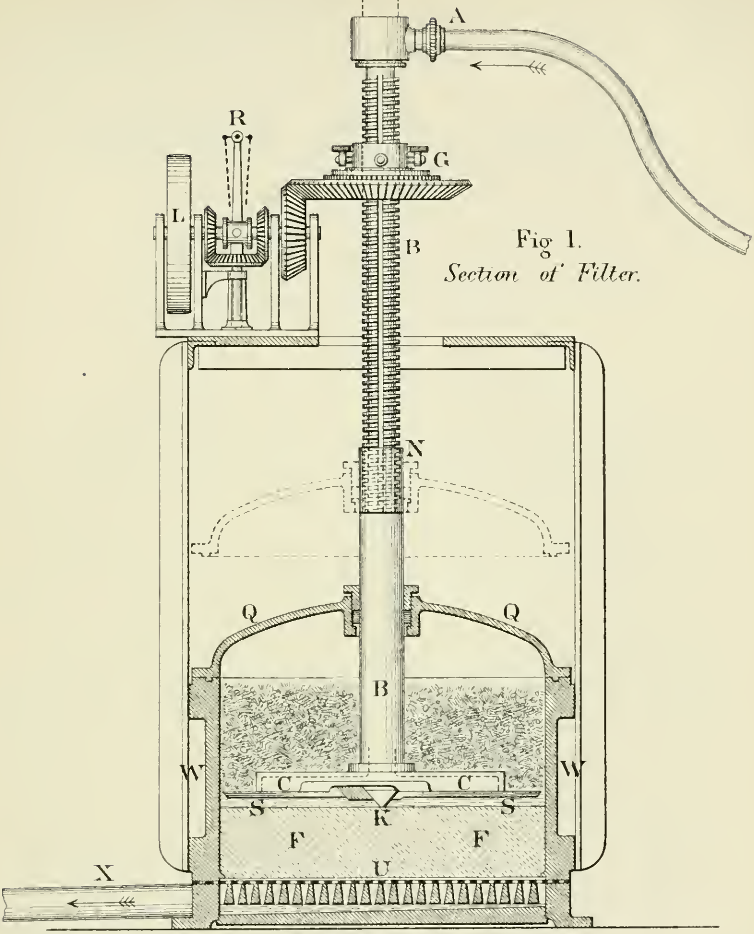


Fig 1.
Section of Filter.

Fig. 2. *Plan of Cutter-plate.*

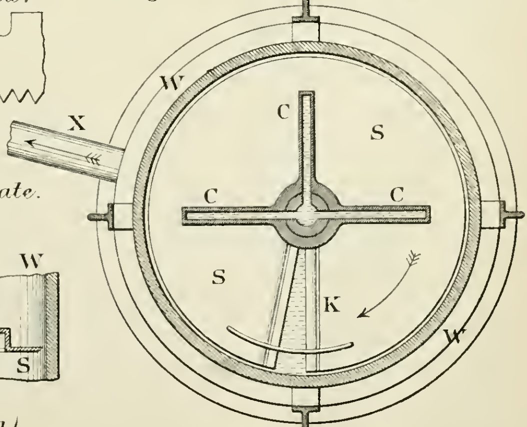


Fig. 4. *Knife enlarged.*

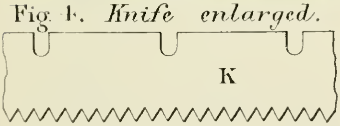
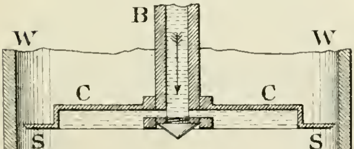


Fig. 3.
Section of Cutter-plate.



Institution of Mechanical Engineers.

PROCEEDINGS.

April 1881.

The Spring Meeting of the Institution was held at the Institution of Civil Engineers, London, on Thursday, 21st April, 1881, at half-past seven o'clock, p.m.; Edward A. Cowper, Esq., President, in the chair.

The Minutes of the last Meeting were read, approved, and signed.

The President announced that the Ballot Lists for the election of New Members had been opened by a Committee of the Council, and that the following candidates had been found to be duly elected:—

MEMBERS.

Joseph Gibson Archbold, . . .	Newcastle-on-Tyne.
Alfred Luther Beattie, . .	Dunedin, New Zealand.
Alfred Blechynden, . . .	Newcastle-on-Tyne.
William Winsland Chilcott, .	Devonport.
James Foyell Lovelock Crosland, .	Manchester.
James Davidson, ...	Dunedin, New Zealand.
William Ferguson, ...	Dublin.
William Wallace Girdwood, .	London.
John Percy Hall, ...	Newcastle-on-Tyne.
George Gatton Melhuish Hardingham,	London.
John Jameson, ...	Newcastle on-Tyne.
Frederick Montague Townshend Lange,	St. Acheul, France.
Edward Pritchard Martin, . .	Blaenavon.
John McKay, ...	Newcastle-on-Tyne.
Arthur Herbert Meysey-Thompson, .	Leeds.

James Mugrave, . . .	Bolton.
Bryce Gray Nichol, . . .	Newcastle-on-Tyne.
Francis Robert Redpath, . .	Montreal, Canada.
Joseph Middleton Rennoldson, . .	South Shields.
William Ross, ...	Dublin.
Ernest Samuelson, ...	Banbury.
Richard Sennett, . . .	Devonport.
Alfred Watkins, ...	Greenwich.
Eustace Ernest Wigzell, . .	London.
Benjamin Frederick Wright, . .	Kobe, Japan.
Louis Edmund Hasselts Yates, .	Jhelum, India.

GRADUATES.

Edward Disney Alexander, . .	Newcastle-on-Tyne.
David Stanley Beesley, . .	Birmingham.
Norman Joseph Lockyer, . . .	Manchester.
Robert Sydney Milles, . .	Wolverhampton.
Philip Powys Rogers, . . .	Warora, India.

The following paper was then read :—

On Riveting, with special reference to Ship-work; by M. le Baron Clauzel, of Toulon.

The President proposed a vote of thanks to the author of the Paper, who was unavoidably prevented from attending, as he had expected to be able to do. The next paper, which was upon the same subject, would now be read, and the two would be discussed together.

The vote of thanks was passed unanimously.

The following paper was then read :—

Results of Experiments on Riveted Joints, made for the Institution of Mechanical Engineers; by Professor Alex. B. W. Kennedy, of London.

The two papers were then discussed together, and at 10 p.m. the discussion was adjourned to the following evening.

The Adjourned Meeting of the Institution was held at the Institution of Civil Engineers, London, on Friday, 22nd April, 1881, at half-past seven o'clock, p.m.; Edward A. Cowper, Esq., President, in the chair.

The discussion on Baron Clauzel's and Professor Kennedy's papers was resumed, and concluded.

A hearty vote of thanks was passed to Professor Kennedy for his very careful and elaborate experiments, and for his paper.

The following paper was then read and discussed:—

On Thrashing Machinery; by Mr. W. Worby Beaumont, of London.

A vote of thanks was passed unanimously to Mr. Beaumont for his paper.

The President said he had now the pleasant duty to perform of proposing a vote of thanks to the Institution of Civil Engineers, for their kindness in granting the use of their rooms for the meeting.

The vote of thanks was carried by acclamation.

The President said he had also to announce that the Newcastle meeting had been definitely fixed to commence on Tuesday, 2nd August. Papers had been already promised of a very interesting character, and there would be various excursions in the neighbourhood. A strong committee had been formed to arrange the details, and there was every expectation of a very pleasant and instructive meeting.

The Meeting then terminated.

[NOTE.—The First Report of the Committee on Riveted Joints, circulated amongst the Members in January 1880, is now published, by order of the Council, after revision, and is inserted after the Discussion on Riveted Joints, commencing on p. 301.]

ON RIVETING, WITH SPECIAL REFERENCE TO SHIP-WORK.

By M. Le Baron CLAUZEL, of Toulon.

Since the strength of any riveted structure depends on that of the riveted joints which it contains, it is evident that the design of these joints is of no less importance than that of the structure itself. Unfortunately the exact strength of a riveted joint is not a matter which it is easy to determine; and instead of our having precise laws on this point, similar to those for the ordinary strength of materials, the practice is guided by rules which are founded on no fixed principles, and vary widely in different localities. It will suffice to cite, as a single instance of the prevailing confusion, that in many establishments it is the rule to give exactly the same pitch to a joint, whether single or double riveted; this pitch being about a mean between the two which would be adopted, in good practice, for the two cases.

Various simple formulæ have indeed been given for determining the pitch of rivets, in the ordinary cases where two plates of equal thickness are joined by one or by two rows of rivets. These however are little used in practice, doubtless because they fail to give all that is necessary, and in many cases are wholly inapplicable. Again, Sir Edward Reed, in his Treatise on Iron Shipbuilding, gives a mode of calculating the strength of any riveted joint by determining the breaking stress under all possible combinations of circumstances; but this mode is too cumbrous for practical use, and moreover serves only to show what is the strength of any particular design, not to show what design will give the greatest strength possible.

With a view to establish the true method of calculation on this subject, the problem may be stated in the following general form:—

"In a riveted joint, made with any given number of rows of rivets,

what should be the pitch in each row, so that the resistance of the joint may be the same for each one of the several modes in which rupture may take place?"

This problem once solved, it will be easy to answer the following supplemental questions:—

(*a*) How must a joint be designed to have a given resistance?

(*b*) What is the maximum resistance to be obtained from a joint having a given number of rows of rivets?

Let us first consider the case of two plates, united by *n* rows of rivets, as in Fig. 1, Plate 27. If we calculate the total resistance of the rivets and plate which must be broken, for each mode in which rupture may take place, it is evident that the least of these resistances will represent the real strength of the joint; and that for all the other modes of fracture the joint is unnecessarily strong. Of all these modes the simplest is that in which one plate tears through the row of rivets furthest from its edge. The resistance of the plate for this mode of rupture is simply the tensile resistance of the plate × the net section. Thus we have the following Fundamental Principle: "*The resistance for any mode of fracture must not be less than the resistance to tearing across at the inside row of rivets; the actual resistance of the joint will then be equal to that resistance. If the joint can be designed so that all these resistances are equal, then it may be called a joint of equal strength throughout.*"

From this principle we may make three deductions:—(1) it is impossible to make any joint so strong as either of the solid plates united by it, unless in some special case it should appear that the weakening due to the inside row of holes is balanced by friction; (2) the pitch in the *inside* rows of rivets should be as great as possible; (3) to insert an additional inside row of rivets, with the same pitch as the rows beyond it, adds absolutely nothing to the strength of the joint.

Instead of commencing with the simplest cases, which would be to repeat the work of previous writers, the author has started with the principle just stated, and has developed it in its most general form. The formulæ thus obtained are therefore general, and the ordinary cases of practice will follow from them as particular cases. In the

present investigation tensile strength is alone considered: other questions, such as those of water or steam tightness, will be taken into account later on.

I. GENERAL FORMULÆ.

To simplify the examination of all the possible modes of rupture, we will first assume the case of a plate A, Fig. 1, Plate 27, united by n rows of rivets to another plate B, which is so strong that it will not give way in any possible case. We will then determine the least thickness which can be given to B, that this condition may hold.

Let a_m = the stress per unit-length of joint, which will tear plate A through the m^{th} row of rivets.

b_m = the stress per unit-length of joint, which will tear plate B through the m^{th} row of rivets.

r_m = the stress per unit-length of joint, which will shear all the rivets of the m^{th} row.

By our hypothesis plate B will never give way, and therefore plate A and the rivets are all with which we have to deal. We will number the rows of rivets 1, 2, 3, &c., beginning from that nearest the edge of the thicker plate B, Fig. 1. Then it is evident that the modes of fracture are the following:—plate A tears through, say, the m^{th} row of rivets, and also shears all the rivets in rows Nos. 1, 2, 3 . . . $(m-1)$: or else the whole of the rivets in rows, 1, 2 . . . n are sheared, and A is not torn.

Let R_m = the stress per unit-length which will tear the plate through the row m, and shear the rivets in rows 1, 2, 3 . . . $(m-1)$;

S $= r_1 + r_2 + \ldots r_{n-1} + r_n$ = the stress which will shear the rivets in the whole of the rows 1, 2, 3 . . . n;

We have then

$$R_m = a_m + r_1 + r_2 + \ldots r_{m-1} = a_m + \Sigma_1^{m-1} r,$$

if we use the symbol Σ to express the summation of a series. It is evident that the stress which will tear the plate through the first row of holes is given by

$$R_1 = a_1,$$

and since by our principle all the other stresses must be equal or greater than the above stress, we have the two formulæ,

$$R_m \geqq R_1, \text{ or } a_m + \Sigma_1^{m-1} r \geqq a_1 \quad . \quad . \quad . \quad . \quad . \quad (1).$$
$$S \geqq R_1, \text{ or } \Sigma_1^n r \geqq a_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2).$$

If the joint is equally strong for every mode of rupture, we shall have

$$R_m = R_1, \text{ or } a_m + \Sigma_1^{m-1} r = a_1,$$
$$S = R_1, \text{ or } \Sigma_1^n r = a_1.$$

From these equations we have :—

$$a_m + \Sigma_1^{m-1} r = \Sigma_1^n r,$$

whence $$a_m = \Sigma_m^n r.$$

Also $$a_m = a_{m-1} - r_{m-1}.$$

The last equation shows that the resistance of the plate at each row should diminish regularly from the first row to the last, in other words that the pitch in each row should diminish regularly. There will often be practical considerations which will not allow this to be carried out; in such cases the joint cannot be made of equal strength throughout, and it will only be necessary to see that the general formulæ (1) and (2) are satisfied.

Hitherto we have not considered the plate B. We have now to see how far the thickness of this plate may be reduced. It is clear by Fig. 2, Plate 27, that plate B may fail, (I.) by tearing through the n^{th} row ; or (II.) by tearing through any other row, as the m^{th}, and shearing the rivets in rows $m + 1$, $m + 2$, . . . n ; or (III.) by tearing through any row, as the m^{th}, and tearing the plate A through any one of the rows $m - 1$, m, or $m + 1$, without shearing ; or (IV.) by tearing through any row, shearing one or more rows of rivets, and tearing the plate A through the row next to that at which the shearing ceases. These various modes of rupture are illustrated in the diagram, Fig. 2, Plate 27.

The stresses F required for rupture under these conditions are given in the Table on the opposite page, using the formula $R_m = a_m + \Sigma_1^{m-1} r$.

Mode of Rupture. (See Fig. 2, Plate 27.)	Stress F producing Rupture (per unit length of joint).
I. B alone breaks, through row n.	$F = b_n$
II. B breaks through row m, and shears rivets in rows $(m+1)$ to n	$F = b_m + \Sigma_{m+1}^{n} r$
IIIa. B breaks through row m, A breaks through row $\overline{m+1}$; no shearing . .	$F = b_m + a_{m+1} = b_m + R_{m+1} - \Sigma_1^m r$
IIIb. B breaks through row m, A breaks through row m; no shearing	$F = b_m + a_m = b_m + R_m - \Sigma_1^{m-1} r$ $> b_m + R_m - \Sigma_1^m r$
IIIc. B breaks through row m, A breaks through row $\overline{m-1}$; no shearing . .	$F = b_m + a_{m-1} = b_m + R_{m-1} - \Sigma_1^{m-2} r$ $> b_m + R_{m-1} - \Sigma_1^m r$
IVa. B breaks through row m, A breaks through row p, rivets sheared in rows $\overline{m+1}$ to $\overline{p-1}$ . . .	$F = b_m + a_p + \Sigma_{m+1}^{p-1} r$ $= b_m + R_p - \Sigma_1^{p-1} r + \Sigma_{m+1}^{p-1} r$ $= b_m + R_p - \Sigma_1^m r$
IVb. B breaks through row m, A breaks through row q, rivets sheared in rows $\overline{q+1}$ to $\overline{m-1}$ . . .	$F = b_m + a_q + \Sigma_{q+1}^{m-1} r$ $= b_m + R_q - \Sigma_1^{q-1} r + \Sigma_{q+1}^{m-1} r$ $> b_m + R_q - \Sigma_1^m r$

None of these values of F ought to be less than the resistance of the joint in the case when B cannot give way. But if the formulæ (1) and (2) are satisfied, all the quantities $R_2\ R_3\ .\ .\ .\ R_n$ and $\Sigma_1^n r$ are equal to or greater than R_1. If then, at each row, the plate B satisfies the general condition

$$b_m \geqq \Sigma_1^m r \quad . \quad . \quad . \quad . \quad . \quad (3),$$

it will be seen that none of the different values of F given in the Table will be less than R_1, and therefore the resistance of the joint will be still $= R_1$.

The expressions for F in the cases IIIa and IVa in the Table show that this condition is not only sufficient but also necessary

in cases where the values of any of the quantities R_2 R_3 . . . R are not greater than, but equal to R_1.

If the formulæ (1) and (2) are equalities, and if we also make the formula (3) an equality, then the least of the resistances which correspond to modes of rupture in which B gives way will also be equal to R_1, and the resistances of the joint will therefore be completely equalised.

Thus we have the following general rules:—

If a joint is to satisfy the Fundamental Principle of the preface, then its elements must satisfy these three general formulæ—

$$a_m + \Sigma_1^{m-1} r \geqq a_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$\Sigma_1^n r \geqq a_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$b_m \geqq \Sigma_1^m r \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3).$$

Of these No. (1) expresses that for any mode of rupture involving tearing of the thinner plate and shearing of rivets, the resistance is equal to or greater than the resistance R_1 to the tearing of the thinner plate across its inside row; No. (2) expresses that the shearing resistance of all the rivets is equal to or greater than R_1; and No. (3) expresses (as shown on the last page) that for any mode of rupture involving tearing of the thicker plate the resistance is also equal to or greater than R_1. When these formulæ are satisfied, the strength of the joint will be represented by R_1 (or a_1); and if they are satisfied as equalities, the resistances of the joint will be equalised throughout.

Hence the mode of procedure will be as follows.

Having given two plates A and B, thicknesses e and e', which are to be united by a joint of given resistance F, we must fix the pitch in row 1, or the row nearest the edge of the thicker plate B, so that the resistance of plate A to tearing along this row may = F. Then the elements in the succeeding rows must be so chosen that the formulæ (1) and (3) may always be satisfied. Now at any row m the values of a_m b_m r_m depend on the diameter and pitch of the rivets; and the formulæ (1) and (3) give (as will be shown later, p. 175) an *inferior limit* of the pitch in terms of the diameter; hence at each row we must take that formula which gives to this inferior limit the greater value. We may follow formula (1) as long as formula (3) is satisfied, and diminish the pitch in each row accordingly, until we reach a row

for which formula (3) is not satisfied; thenceforward we must follow formula (3), and increase the pitch in each row, whereby formula (1) will of course be more than satisfied. Finally, if formula (2) is not satisfied, we must insert one or more additional rows of rivets for that purpose.

As an example we may take the joint shown in Fig. 3, Plate 27, the full calculations for which need not be given. Two plates A B, 430 mm. wide, and respectively 14 and 18 mm. thick, are to be united by a joint giving 95 per cent. of the strength of the solid plate A. Then in row 1 we can only have a single rivet of 22 mm. diameter, $\left(\frac{430-22}{430}=\frac{95}{100}\right)$. We then increase the number of rivets in successive rows, by applying formula (1). That formula would admit eight rivets in the 4th row, but then formula (3) would not be satisfied. It will be satisfied by giving seven rivets; and we then diminish the number in each row, following formula (3). We thus get two rivets for the 6th row, and, as formula (2) is then satisfied, no more rows need be added. The resistance of the whole joint is then given by the resistance of plate A to tearing through the single hole in row 1.

In this operation the width of both plates has been supposed constant throughout the joint; it will be shown hereafter how the width of each may be reduced as its edge is approached.

II. Practical Formulæ.

To reduce to a practical shape the general formulæ of Section I, we must express the quantities a_m, b_m, r_m in terms of what may be called the elements of the joint, *i.e.* the thickness and width of the plates, the diameter and pitch of the rivets.

Our present investigation will concern only Lap-joints, including in these the attachment of a plate to a single cover-plate. The application to Butt-joints with two cover-plates will be made hereafter.

Let e be the thickness of the thinner plate A.

" e' " " thicker " B.

" $\phi=\frac{e'}{e}$ " the ratio of these thicknesses.

Let L_m be the width of A along the m^{th} row of rivets.
,, L'_m ,, width of B along the m^{th} row of rivets.
,, d_m ,, diameter of rivets in the m^{th} row.
,, N_m ,, total number of rivets in the m^{th} row.
,, R ,, tensile resistance of the plate in kg. per sq. mm.
,, R′ ,, shearing resistance of the rivets in kg. per sq. mm., including any resistance due to friction.
,, E_m ,, ratio to diameter of the mean pitch on plate A, of the rivets in row m, or Relative Pitch on plate A.
,, E'_m ,, do. do. for plate B.

Then since $\frac{L_m}{N_m}$ = mean pitch in row m on plate A,

$\frac{L'_m}{N_m}$ = ,, ,, B,

we have $E_m = \frac{L_m}{d_m} \times \frac{1}{N_m}$, $E'_m = \frac{L'_m}{d_m} \times \frac{1}{N_m}$.

With this notation the tensile resistances a_m and b_m of A and B, and the shearing resistance r_m of the rivets, for the m^{th} row, are given by

$$a_m = (L_m - N_m d_m)eR$$

$$b_m = (L'_m - N_m d_m)e'R = (L'_m - N_m d_m)\phi eR$$

$$r_m = \frac{\pi d_m^2}{4} N_m R' = \frac{\pi}{4}\frac{R'}{R}\frac{N_m d_m^2}{e} eR.$$

Using the latter equations, we may omit the factor eR from our calculations, and the resistances obtained will then be the actual resistances divided by eR. We will also write for brevity—

$\frac{\pi}{4}\frac{R'}{R} = K$, a constant supposed known,

$\frac{\pi}{4}\frac{R'}{R} \times \frac{1}{e} = \frac{K}{e} = C$, a constant given by the thickness of the thinner plate.

We may then use equations as follows:—

$$a_m = L_m - N_m d_m = \left(1 - \frac{1}{E_m}\right) L_m$$

$$b_m = (L'_m - N_m d_m)\,\phi = \left(1 - \frac{1}{E'_m}\right) \phi L'_m$$

$$r_m = CN_m d_m^2 = C\frac{d_m}{E_m}L_m = C\frac{d_m}{E'_m}L'_m.$$

Substituting these values in the three general formulæ of Section I., we obtain the following Table :—

General Formulæ.	Practical Formulæ.	
$R_m \geqq R_1$ or $a_m + \Sigma_1^{m-1} r \geqq a_1$	$L_m - N_m d_m + C\Sigma_1^{m-1} N d^2 \geqq L_1 - N_1 d_1$ or $N_m d_m \leqq L_m + N_1 d_1 - L_1 + C\Sigma_1^{m-1} N d^2$	(1)
$S \geqq R_1$ or $\Sigma_1^n r \geqq a_1$	$C\Sigma_1^n N d^2 \geqq L_1 - N_1 d_1$	(2)
$b_m \geqq \Sigma_1^m r$	$(L'_m - N_m d_m)\phi \geqq C\Sigma_1^m N d^2$ or $N_m d_m\ (\phi + C d_m) \leqq L'_m \phi - C\Sigma_1^{m-1} N d^2$	(3)

It will be seen that (1) and (3) give a superior limit to the number of rivets in row m, or an inferior limit to their pitch, when the elements in the preceding rows have been determined. Hence we must leave (1) and follow (3), as soon as we have for the row m

$$L_m - L_1 + N_1 d_1 + C\Sigma_1^{m-1} N d^2 \geqq \frac{L'_m \phi - C\Sigma_1^{m-1} N d^2}{\phi + C d_m}$$

$$\text{or} \qquad \Sigma_1^{m-1} N d^2 \geqq \frac{L'_m \phi - (L_m - L_1 + N_1 d_1)(\phi + C d_m)}{C(1 + \phi + C d_m)} \quad . \ . \ . \ . \quad (4)$$

The above formulæ are perfectly general, and allow of the diameter of rivets and width of plate varying for each row. We will now simplify them as follows :—

1. Let the width L of each plate be constant, but let the rivet diameter d vary. Then the formulæ become—

$$N_m d_m \leqq N_1 d_1 + C\Sigma_1^{m-1} N d^2, \qquad \text{or} \quad \frac{1}{E_m} \leqq \frac{1}{E_1} + C\Sigma_1^{m-1} \frac{d}{E} \quad . \quad (1a)$$

$$C\Sigma_1^n N d^2 \geqq L - N_1 d_1, \qquad \text{or} \quad C\Sigma_1^n \frac{d}{E} \geqq 1 - \frac{1}{E_1} \quad . \ . \quad (2a)$$

$$N_m d_m (\phi + C d_m) \leqq L\phi - C\Sigma_1^{m-1} N d^2, \quad \text{or} \quad \frac{\phi + C d_m}{E_m} \leqq \phi - C\Sigma_1^{m-1} \frac{d}{E} \qquad (3a)$$

2. Let the width L vary, but let the rivet diameter d be constant. Then the formulæ become—

$$L_m \geqq L_1 - N_1 d + N_m d - Cd^2 \Sigma_1^{m-1} N \quad . \quad . \quad . \quad . \quad (1b)$$

$$\Sigma_1^n N \geqq \frac{\frac{L_1}{d} - N_1}{Cd} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2b)$$

$$L'_m \geqq \frac{Cd^2}{\phi} \Sigma_1^m N + N_m d \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3b)$$

3. Lastly let both widths and diameters be constant, which is the most common case. Then the formulæ become—

$$N_m \leqq N_1 + Cd\Sigma_1^{m-1} N, \qquad \text{or} \qquad \frac{1}{E_m} \leqq \frac{1}{E_1} + Cd\Sigma_1^{m-1} \frac{1}{E} \quad . \quad . \quad (\text{I.})$$

$$\Sigma_1 N \geqq \frac{\frac{L}{d} - N_1}{Cd}, \qquad \text{or} \qquad Cd\Sigma_1^n \frac{1}{E} \geqq 1 - \frac{1}{E_1} \quad . \quad . \quad . \quad (\text{II.})$$

$$N_m \leqq \frac{\frac{L}{d}\phi - Cd\Sigma_1^{m-1} N}{\phi + Cd}, \qquad \text{or} \qquad \frac{\phi + Cd}{E_m} \leqq \phi - Cd\Sigma_1^{m-1} \frac{1}{E} \quad (\text{III.})$$

Finally, formula (4), which shows at what row m' we must leave formula (I.) and begin to follow formula (III.), becomes—

$$\left.\begin{aligned} &\Sigma_1^{m'-1} N \geqq \frac{\frac{L}{d}\phi - N_1(\phi + Cd)}{Cd(1 + \phi + Cd)} \\ \text{or} \qquad &\phi \leqq \frac{Cd[N_1 + (1 + Cd)\Sigma_1^{m'-1} N]}{\frac{L}{d} - N_1 - Cd\Sigma_1^{m'-1} N} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (\text{IV.})$$

The Actual Resistance of the joint is equal to the resistance of plate A at the first row of rivets, and is therefore given by $(L_1 - N_1 d_1)eR$. What is usually required however is not the actual resistance, but the Proportion of Strength for the joint, that is the ratio between the resistance of the joint and that of the solid plate. If we call this Proportion of Strength ρ, we have

$$\rho = \frac{(L_1 - N_1 d_1)eR}{L_1 eR} = 1 - \frac{N_1 d_1}{L_1} = 1 - \frac{1}{E_1} \quad . \quad . \quad . \quad (5)$$

and inversely $\qquad E_1 = \dfrac{1}{1 - \rho}, \qquad N_1 = \dfrac{L_1}{d_1}(1 - \rho) \quad . \quad . \quad . \quad . \quad (6).$

Equation (6) will give the number of rivets in the first row for any given proportion of strength.

In this calculation we have assumed that the strength of the

plate, per unit of sectional area, was the same along a line of rivets as in the solid plate. Where the holes are punched however, it is generally held that some reduction in the strength per unit area takes place. In such cases the value of ρ given above ought to be multiplied by the ratio of the reduced to the original strength. This ratio is given for iron as 0·88 by Barba, and as 0·81 by Reed; the values given by other experimenters differ widely.* It appears however from M. Barba's researches that the actual damage is only done to a very narrow ring of metal round the hole; and if so it is evident that the loss of strength will be less as the pitch is greater. Hence for a joint such as we have been discussing, in which there is only one rivet in the inside row, this effect may probably be neglected. As a rule, in the general calculation for the proportion of strength in a joint, it seems better to take no account of the weakening effect of punching, in the absence of accurate data by which to calculate it exactly. When we come however to numerical applications, then, in taking values for the tensile strength of the plate, we shall assume that the ratio of the reduced to the original strength is for iron 0·85, a mean figure between the two values stated above. For steel it will be assumed that, where the holes are not drilled, they will be always rimered out after punching, and that the damage due to punching will be thus destroyed.

Again, in the preceding theory the tensile resistance of the plate through any row of rivets was given in terms involving the diameter of rivet, which is less by about 1 mm. (0·04 in.) than the diameter of the hole; this may be taken account of by simply adding 1 mm. to the mean pitch calculated by the formulæ. The same remark applies to the conical enlargement of the holes due to punching or countersinking.

III. *Application of the Practical Formulæ.*†

We will now proceed to the application of the general formulæ investigated in Section II.; and for the present we will confine ourselves to the simplified forms I.–IV., in which the widths of the

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* See First Report of Committee on Riveted Joints, pp. 323, 324.

† The whole of the formulæ developed in this section are brought together in Table A, appended, page 203.

plates and the diameters of the rivets are the same throughout the joint. We will consider three cases :—

1. The thickness of one plate is given, and that of the other may be taken at pleasure;

2. Both plates have the same thickness;

3. The thicknesses are unequal, both being given.

The formulæ to be applied are as follows :—

$$N_m \leqq N_1 + Cd\Sigma_1^{m-1} N \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (\text{I.})$$

$$\Sigma_1^n N \geqq \frac{\frac{L}{d} - N_1}{Cd} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (\text{II.})$$

$$N_m \leqq \frac{\frac{L}{d}\phi - Cd\Sigma_1^{m-1}N}{\phi + Cd} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (\text{III.})$$

We must first choose the diameter of the rivets, and then the pitch in the first row: the latter may be arbitrary, or may be fixed in accordance with a required proportion of strength by means of formula (6), namely

$$E_1 = \frac{1}{1-\rho} \qquad \text{or} \qquad N_1 = \frac{L}{d}(1 - \rho).$$

Then formula (I.) gives the number of rivets in the successive rows, as long as the superior limit which it assigns to that number is less than the limit assigned by formula (III.). As soon as this ceases to be true, that is as soon as we have for any row m'

$$\Sigma_1^{m'-1}N \geqq \frac{\frac{L}{d}\phi - N_1(\phi + Cd)}{Cd(1 + \phi + Cd)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (\text{IV.}),$$

then we must follow (III.) in fixing the number of rivets in the successive rows, including the row m'. Lastly (II.) fixes the limit for the total number of rivets, and thus fixes the number of rows required to furnish any given proportion of strength.

Conversely, if the number of rows is given, the pitch in the first row is no longer arbitrary: but we can calculate by the same formula the widest pitch admissible in the first row, and the resulting proportion of strength.

The three cases mentioned have been fully worked out on this basis but the results alone will here be given.

Case 1.—*Thickness of A given, thickness of B to be taken at pleasure.*

(*a*) *Proportion of strength fixed beforehand.* The relative pitch in row 1 is then fixed by formula (5). For all the other rows we can follow formula (I.), because the thickness of B may be chosen to suit. The total number of rivets will be given by (II.). We have finally to give the thickness of B. If we have used the formula (I.) as an equation, so as to equalise the strength for all the rows, then the pitch decreases regularly for each row from 1 to n: and if formula (III.) (which may be written $\left(\frac{L}{d} - N_m\right)\phi \geqq Cd\Sigma_1^m N$) is satisfied for the last row n, it will certainly be satisfied for the other rows, because as we go backwards from row n the expression on the left hand increases, while that on the right hand decreases. If the pitch has not been diminished from row 1 to row n so rapidly as above, but if care has been taken *never to increase* it in a succeeding row, the same will still be true. Hence the formulæ which will determine all the elements of the joint in this case are the following:—

$$N_m \leqq N_1 + Cd\Sigma_1^{m-1}N \quad \ldots\ldots\ldots \quad \text{(I.)}$$

$$\Sigma_1^n N \geqq \frac{\frac{L}{d} - N_1}{Cd} \quad \ldots\ldots\ldots \quad \text{(II.)}$$

$$\phi \geqq \frac{Cd\Sigma_1^n N}{\frac{L}{d} - N_n} \quad \ldots\ldots\ldots \quad \text{(V.)}$$

(*b*) *Number of rows of rivets fixed beforehand.* The proportion of strength is not arbitrary, and the pitch in row 1 can no longer be fixed at pleasure. It is easily shown that if formula (II.) is to be satisfied with the given number of rows, whilst at the same time formula (I.) is satisfied for each row, then for any row m we must have $\frac{L}{d} \times \frac{1}{(1 + Cd)^{n-m}} \leqq N_1 + Cd\Sigma_1^m N \quad \ldots\ldots \quad$ (VI.).

This formula gives the minimum number of rivets in the row m, while (I.) gives the maximum; and therefore we shall be safe in taking any number between these two.

Applying this formula to row 1 we have

$$\frac{L}{d} \times \frac{1}{(1 + Cd)^{n-1}} \leqq N_1(1 + Cd); \text{ or } N_1 \geqq \frac{L}{d} \times \frac{1}{(1 + Cd)^n} \quad \text{(VII.)}$$

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This gives for the greatest possible proportion of strength in this case,

$$\rho \leqq 1 - \frac{1}{(1 + Cd)^n}.$$

Hence the formulæ for calculating the elements of the joint in this case are :—

$$N_1 \geqq \frac{L}{d} \times \frac{1}{(1+Cd)^n} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(VII.)}$$

(Inferior limit for the number of rivets in row 1)

$$\begin{cases} N_m \leqq N_1 + Cd\Sigma_1^{m-1}N \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(I.)} \\ N_m \geqq \frac{L}{d} \times \frac{1}{Cd(1 + Cd)^{n-m}} - \frac{N_1 + Cd\Sigma_1{}^{m-1}N}{Cd} \quad . \quad . \quad . \quad . \quad \text{(VI.)} \end{cases}$$

(Limits to the number of rivets in any row m)

$$\phi \geqq \frac{Cd\Sigma_1^n N}{\frac{L}{d} - N_n} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(V.)}$$

(Least admissible thickness of the plate B).

(c) *Joint of Equal Strength throughout.* To obtain the maximum proportion of strength for a given number of rows, we must make formula (VII.) an equality, and equalise the strength in the other succeeding rows. Then formula (I.) also becomes an equality, and takes the form

$$N_m = (1 + Cd)N_{m-1} . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(I}a.\text{)}$$

Hence we have the simple rule that in a joint of equal strength throughout, the number of rivets increases in a Geometrical Progression, whose ratio is $(1 + Cd)$.

The other formulæ become in this case

$$N_1 = \frac{L}{d} \times \frac{1}{(1 + Cd)^n} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(VII}a.\text{)}$$

$$\rho = 1 - \frac{1}{(1 + Cd)^n}$$

$$N_m = \frac{L}{d} \times \frac{1}{(1 + Cd)^{n-m+1}}$$

$$\phi \geqq \frac{(1 + Cd)^n - 1}{Cd(1 + Cd)^{n-1}} \text{ or } \phi \geqq \rho \times \frac{1 + Cd}{Cd}.$$

Before leaving this case, it will be well to consider what will be the result when there is only one row of rivets. Formula (I.) then becomes useless. Formula (II.) becomes

$$N_1 \geqq \frac{\frac{L}{d}}{1 + Cd};$$

or, since $N_1 = \frac{L}{d} \times \frac{1}{E_1}$, $\qquad E_1 \leqq 1 + Cd.$

Formula (V.) becomes $\qquad \phi \geqq 1.$

The maximum Proportion of Strength is given by

$$\rho = 1 - \frac{1}{1 + Cd} = \frac{Cd}{1 + Cd}; \text{ and } E_1 = 1 + Cd.$$

If, for other reasons, it is necessary to make the pitch wider than the limit given by $E = 1 + Cd$, then the resistance of the plate is in excess, and the strength of the joint depends on that of the rivets. The Proportion of Strength is then given by

$$\rho = \frac{Cd^2N \times eR}{LeR} = \frac{Cd^2N}{L} = \frac{Cd}{E}.$$

It thus decreases exactly in proportion as the pitch increases. It is important to note this, because it often happens, especially with steel joints, that the pitch is made wider than the formula ($E = 1 + Cd$) allows, in the fear that too much will be taken out of the plate. It is clear that the effect of this is simply to diminish the strength of the joint.

CASE 2.—*Both plates of the same thickness.*

Here the joint will of course be symmetrical. The pitch for the successive rows up to the middle of the joint will be fixed by (I.), and the total number of rivets by (II.). Formula (III.) becomes useless.

(*a*) *Proportion of strength fixed beforehand.* Formula (I.) has the usual form,

$$N_m \leqq N_1 + Cd\,\Sigma_1^{m-1}N \quad . \quad . \quad . \quad . \quad . \quad (I.)$$

Formula (II.) takes two forms, according as the number of rows is odd or even:

$$\left.\begin{array}{lll} \text{If } n = 2M - 1, & N_M + 2\,\Sigma_1^{M-1}N \geqq \dfrac{\frac{L}{d} - N_1}{Cd}, \\ \quad ,, \; n = 2M, & 2\,(N_M + \Sigma_1^{M-1}N) \geqq \dfrac{\frac{L}{d} - N_1}{Cd} \end{array}\right\} (II'.)$$

(*b*) *Number of rows of rivets fixed beforehand.* The pitch in the first row is no longer arbitrary. To satisfy formula (II′.) and at the same time satisfy formula (I.) for each row, we must have

$$\left.\begin{aligned}
&\text{If } n = 2\mathrm{M}-1, \quad \frac{\frac{\mathrm{L}}{d}+\mathrm{N}_1}{(2+\mathrm{C}d)\,(1+\mathrm{C}d)^{\mathrm{M}-m-1}} \leqq \mathrm{N}_1 + \mathrm{C}d\,\Sigma_1^m \mathrm{N}\\
&\text{or} \quad \mathrm{N}_m \geqq \frac{\frac{\mathrm{L}}{d}+\mathrm{N}_1}{\mathrm{C}d\,(2+\mathrm{C}d)\,(1+\mathrm{C}d)^{\mathrm{M}-m-1}} - \frac{\mathrm{N}_1+\mathrm{C}d\,\Sigma_1^{m-1}\mathrm{N}}{\mathrm{C}d}\\
&\text{If } n = 2\mathrm{M}, \quad \frac{\frac{\mathrm{L}}{d}+\mathrm{N}_1}{2\,(1+\mathrm{C}d)^{\mathrm{M}-m}} \leqq \mathrm{N}_1 + \mathrm{C}d\,\Sigma_1^m \mathrm{N}\\
&\text{or} \quad \mathrm{N}_m \geqq \frac{\frac{\mathrm{L}}{a}+\mathrm{N}_1}{2\,\mathrm{C}d\,(1+\mathrm{C}d)^{\mathrm{M}-m}} - \frac{\mathrm{N}_1+\mathrm{C}d\,\Sigma_1^{m-1}\mathrm{N}}{\mathrm{C}d}
\end{aligned}\right\}\ \text{(VI.′)}$$

Formula (VI.′) fixes a minimum for the number of rivets in any row, while (I.) fixes a maximum. Applying (VI′.) to row 1 we get—

$$\left.\begin{aligned}
&\text{If} \quad n = 2\mathrm{M}-1, \quad \mathrm{N}_1 \geqq \frac{\mathrm{L}}{d} \times \frac{1}{(2+\mathrm{C}d)\,(1+\mathrm{C}d)^{\mathrm{M}-1} - 1}\\
&\text{if} \quad n = 2\mathrm{M}, \quad \mathrm{N}_1 \geqq \frac{\mathrm{L}}{d} \times \frac{1}{2\,(1+\mathrm{C}d)^{\mathrm{M}} - 1}
\end{aligned}\right\}\text{(VII.′)}$$

This formula gives the maximum Proportion of Strength, $\rho = 1 - \mathrm{N}_1\frac{d}{\mathrm{L}}$, which can be obtained with a given number of rows. In that case the joint must be of equal strength throughout, and we must put the sign = in formulæ (I.) and (VII.′).

Case 3.—*Plates A and B of different thicknesses, both given.*

(*a*) *Proportion of strength given.* The number of rivets in row 1 is then fixed, and the method is the same as before. We follow the formula

$$\mathrm{N}_m \leqq \mathrm{N}_1 + \mathrm{C}d\,\Sigma_1^{m-1}\mathrm{N} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(I.)}$$

up to the row m', for which

$$\Sigma_1^{m'-1}\mathrm{N} \geqq \frac{\frac{\mathrm{L}}{d}\,\phi - \mathrm{N}_1\,(\phi + \mathrm{C}d)}{\mathrm{C}d\,(1+\phi+\mathrm{C}d)} \quad . \quad . \quad . \quad . \quad \text{(IV.)};$$

from the row m' inclusive we follow the formula

$$N_m \leqq \frac{\frac{L}{d}\phi - Cd\,\Sigma_1^{m-1}N}{\phi + Cd} \quad . \quad . \quad . \quad . \quad . \text{(III.)};$$

the total number of rivets being given by

$$\Sigma_1^n N \geqq \frac{\frac{L}{d} - N_1}{Cd} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \text{(II.)}.$$

(*b*) *Number of rows given.* When the thickness of plate B was arbitrary, with n rows of rivets, the maximum pitch in row 1 was given by formula (VII*a*), Case 1 (*c*), and that B might be thick enough to allow of this pitch, we had to take

$$\phi \geqq \frac{(1 + Cd)^n - 1}{Cd(1 + Cd)^{n-1}}.$$

If the actual value of ϕ is above this limit, the case becomes the same as Case 1 (*c*). But if ϕ be below this limit, the maximum value of N_1, which corresponds to the joint of equal resistance throughout, cannot be calculated by any simple method. In the special case where there are only 2 rows of rivets, and where the ratio ϕ of the thicknesses lies between 1 and $\frac{2 + Cd}{1 + Cd}$, the combination of the formulæ (II.) and (III.) gives

$$N_1 \geqq \frac{L}{d} \times \frac{\phi - Cd(\phi - 1)}{\phi + Cd(\phi + 1)}.$$

This formula gives the greatest practicable Proportion of Strength.

The number of rivets in row 2 is fixed by combining the formulæ

$$N_2 \geqq \frac{\frac{L}{d} - N_1(1 + Cd)}{Cd} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \text{(II.)}$$

$$N_2 \leqq \frac{\frac{L}{d}\phi - Cd\,N_1}{\phi + Cd} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \text{(III.)}$$

IV. GENERAL OBSERVATIONS.

Width.—In our calculations hitherto we have supposed the width L of the joint to be given. In many cases this is true; *e.g.*, in ship work, for the keelsons, frames, &c. For certain longitudinal joints,

such as those of the strakes in shipbuilding or the webs in girders, the joint is divided into equal intervals by the frames or stiffeners, and these intervals may be taken for our purpose as the widths of the joints. In other cases, where the widths are practically indeterminate, we must take the riveting per unit length of the joint; L will then be the unit length, and N the number of rivets per unit length instead of the total number in a row.

Butt-joints.—Hitherto we have spoken only of lap-joints. All that has been said however applies precisely to a butt-joint with a single cover-plate, and the same rules will determine the riveting of each plate to the cover. When the two plates are of the same thickness, the riveting on both sides of the joint will be identical, and the strength the same. If the plates are of unequal thickness, and it is desired to make both sides of the joint equally strong, special calculations must be made for each. If the proportion of strength on the side of the thinner plate, as referred to that plate when solid, is called ρ, then the proportion of strength ρ' on the other side referred to the thicker plate, will be given by

$$\rho' = \rho \times \frac{e}{e'}$$

where e and e' are the thicknesses of the plates. But it is simpler, and generally sufficient, only to calculate the riveting on the side of the thinner plate, and to adopt the same proportions for the side of the thicker plate, which will then be certainly not less strong than the other.

It is also easy to deduce from the rules established others which apply to butt-joints with two cover-plates. In this case each rivet is in double shear, and its resistance would appear at first sight to be doubled. But although this applies to the shearing resistance proper, it does not apply to that due to the friction of the plates; and hence we might expect that the resistance would be somewhat less than double, as some writers appear to have found. The experiments on this point are not however numerous and precise enough to give accurate data; and for the present it seems better to retain the usual assumption that the resistance is exactly double.

Further, the resistance to tearing of the cover-plates is determined for any row by the sum of their thicknesses. Hence all we shall have to do, in applying our formulæ to butt-joints with two covers, will be to substitute 2 C for C (that is, to double the shearing resistance of the rivets in each row), and to write for the thickness e' of the plate B the sum of the thicknesses of the two covers.

Practical Proportion of Strength.—We have now the means of designing a joint so as to give any desired proportion of strength. Now when we have to unite two plates which do not suffer any diminution of width away from the joint—*e.g.* two plates in tension, like the flange of a girder—it is evidently desirable to make the proportion of strength the greatest possible. This will be realised as already pointed out, by placing in row 1 a single rivet of the smallest diameter allowable; of which an example will be given further on.

If however the plates are weakened away from the joint, *e.g.* by holes being cut in them or some other piece attached to them, it is clear that there is no use in giving to the joint a greater resistance than that of the plate at its weakest section. If we suppose this latter resistance to be given, say $0 \cdot 85$ that of the solid plate, then it will suffice to give the joint a proportion of strength $= 0 \cdot 85$; and our formulæ will then determine for us the number of rows of rivets, and the pitch in each row.

Lastly, if the joint has to be water-tight, the pitch in the row next the caulking edge A, Fig. 4, Plate 28, must not exceed a certain limit, which the ordinary practice of shipyards has fixed at about $4\frac{1}{2}$ diameters. This then must be the pitch for the n^{th} row in a lap-joint, or in a butt-joint with one cover-plate, which has to be made water-tight. But by using a cover-plate thicker than the plates to be joined, Fig. 4, we may diminish the pitch in going from the 1^{st} to the n^{th} row as much as we please; and since the strength of the joint, if properly designed, depends only on the pitch in row 1, we can still give the joint any strength required. If, on the other hand, we adopt two cover-plates, which at first sight would appear preferable, then the caulking must take place at the point B, Fig. 5,

Plate 28, that is to say, on the edge next to row 1; and therefore it is in row 1 that the pitch must not exceed $4\frac{1}{2}$ diameters. *Hence in a water-tight joint with two covers it is not possible to obtain a greater proportion of strength than* $1 - \frac{1}{4\cdot 5}$, *or* $0\cdot 78$.

It is true that in the latter case the joint is symmetrical on its two sides, and the tensile stress may seem to be transmitted across it with less fatigue to the rivets. But this fatigue, which would be serious with a single riveted lap-joint, loses much of its importance in a butt-joint with one cover, and having two or three rows of rivets. Hence it appears that, if we wish to give to a water-tight joint a higher proportion of strength than $0\cdot 78$, as will often be the case, it is better, instead of adopting two covers, to employ a single cover-plate of greater thickness, proportioning this thickness by our formulæ, so as to give the proportion of strength desired. Many cases of this kind occur in ship-work.

Narrowing of the plates towards the edge.—In applying the practical formulæ given on p. 176, we determine the number of rivets in each row on the supposition that the widths of the two plates are equal and constant. But from p. 172 it is evident that from row 1 up to the row at which we cease to follow formula (I.) and adopt formula (III.), this latter formula is more than satisfied. Hence the pitch in plate B need not be so large as that actually given; it will be sufficient that it satisfies the more general formula (3*b*). Similarly in the rows in which formula (III.) is used, the pitch on the plate A (3*b*) need not be so large, and it would be sufficient to satisfy the general formula (1*b*). In consequence, after having calculated the number of rivets in each successive row, as if the two widths were the same throughout, we may fix the minimum width for each plate, from what may be called the row of transition to its edge, by means of the two following formulæ:—

From row 1 to row of transition,

$$L'_m \geqq N_m d + \frac{Cd^2}{\phi} \Sigma_1^m N \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3b)$$

From row of transition inclusive to row n,

$$L_m \geqq L_1 - N_1 d + N_m d - Cd^2 \Sigma_1^{m-1} N \quad . \quad (1b)$$

If the two thicknesses are equal, it will suffice to diminish the width towards both edges according to the formula (3b). We may in practice reduce the width for each successive row by shearing the plate along straight lines, such that at each row they leave a width above the limit marked by the formulæ (1b) and (3b). For example, in the joint, Fig. 6, Plate 28, the riveting of the rows 1, 2, and 3 has been calculated according to formula (I.), and that of rows 4 and 5 according to formula (III.). The width of plate B is then reduced from row 4 in one direction, and that of plate A in the other direction, as shown in Fig. 7; the pitch of the rivets being modified to suit. This reduction of width has the double advantage of assisting the equalising of the joint, and of effecting an economy in the weight, which in some cases may be not inconsiderable.

Diameter of Rivets.—First, if we have to give to a joint a certain proportion of strength, it is necessary that the shearing resistance of all the rivets should be not less than the tensile resistance of the plate along row 1. The total sectional area of the rivets is therefore a fixed quantity, and their number will thus be less as their diameter is greater. Next, if we proceed to examine the greatest proportion of strength which it is possible to obtain with a given number of rows, and which corresponds to the joint of equal resistance, we see that the proportion of strength $\rho = 1 - \frac{N_1 d}{L}$ is greater as $\frac{N_1 d}{L}$ is less. Now we have seen in Section III. that the minimum value of the product $N_1 d$ is less as the diameter of the rivets is greater. Hence, *with a given number of rows, the maximum proportion of strength is greater as the rivet diameter is greater.* Lastly, for the same thickness of plate, the rivet diameter should increase, other things being equal, with the strength of the material of which the plates are made. For formula (II.), which fixes the least number of rivets which is allowable, is

$$\Sigma_1^n N = \frac{\frac{L}{d} - N_1}{Cd} = \frac{1 - \frac{N_1 d}{L}}{Cd^2} \times L = \rho \times \frac{L}{Cd^2}.$$

Hence, for a given proportion of strength ρ, the minimum number of rivets varies inversely as Cd^2: in other words, to obtain the same

proportion of strength with the same number of rivets, the diameter of the rivets must vary inversely as $\sqrt{C}$; or, speaking more generally, must be greater as the tensile strength R of the plate is greater, since C varies inversely as R. One result of this principle is, as will be seen further on, that in many cases, and especially in the case of single-riveted lap-joints, the rivets should be given a larger diameter with steel plates than with iron.

V. Numerical Applications.

Determination of Constants.—To apply the preceding theory to any particular case, we must first determine the numerical values of the constants R and R′, which represent respectively the tensile resistance of the plate and the resistance of the rivet in single shear.

With regard to the value of R, we shall adopt 32 kg. per sq. mm. (20·2 tons per sq. in.) for iron plates drilled, and 42 kg. (26·5 tons) for steel plates; the effect of punching has already been considered, p. 177.

With regard to the value of R′, the resistance of a rivet is not the same as the shearing resistance of a rivet bar as sheared between two plates. The process of riveting has two effects. It places the rivet, when cold, in a state of tension, which diminishes its shearing strength; and it also, in consequence of this tension, produces a friction between the plates, which goes to increase the apparent shearing strength. It is not easy to calculate these two effects, and the experiments made on the subject are not sufficiently numerous to ascertain them. The permanent elongation of the rivet depends upon the compression produced on the plate by the rivet head, and in caulking. This elongation will therefore depend on the form of the rivet head, as will also the friction which it produces; a result which appears from the figures given in Reed on Iron Shipbuilding. On the whole we shall adopt 35 kg. per sq. mm. (22 tons per sq. in.) as the total resistance of an iron rivet in single shear: steel rivets will not be considered. Taking this value for R′, it is easy to calculate the value of the coefficient C, which is the expression entering into the formula. This expression is given by

$$C = \frac{K}{e}, \text{ where } K = \frac{\pi}{4}\,\frac{R'}{R}.$$

Here the values of R and of K under different circumstances will be taken as in the following Table :—

Material.	Value of R.		Corresponding Value of K.
	Kg. per sq. mm.	Tons per sq. in.	
Iron Plates, Punched...............	27·9	17·7	1·00
„ Drilled	32·4	20·6	0·85
Steel Plates, Drilled or rimered out after punching...............	42·1	26·7	0·65

The value of C will be found on dividing K by the thickness e of the thinner plate.

The values here given for the constants are not of course intended to be final, and must be corrected by actual experiment. Their actual values have nothing to do with the theory of the subject; and what is required from actual experiment is to ascertain the values which best satisfy the formulæ we have deduced.

Diameter of Rivets.—We have already pointed out the general advantage, so far as strength is concerned, of making the diameter of the rivets as large as possible. It is easy to give theoretically an inferior and a superior limit for their diameter, fixed respectively by the power of the punch to stand, in the case of punched plates, and by the bearing resistance of the rivets in the holes. But the limits thus marked out are generally much wider than those which are fixed by practice. If the rivet is too large, the head may be liable to be pulled off under the longitudinal strain to which it is subjected; this fixes a superior limit to the diameter, which may be reached in the case of butt-joints with two covers.

The following Table gives the limits within which the diameter of the rivets varies for various thicknesses of plate, according to the practice of a large number of works. The thickness here given is that of the thinner of the two plates to be joined, and the diameter of the rivets varies by intervals of two millimetres (0·079 in.), between the limits given.

TABLE OF RIVET DIAMETERS.

Plate Thickness.		Rivet Diameters.		Corresponding Values of $Cd = K\frac{d}{e}$.		
Milli-metres.	Nearest Sixteenths of an Inch.	Milli-metres.	Nearest Sixteenths of an Inch.	Iron Plates Punched.	Iron Plates Drilled.	Steel Plates.
4	3	8 to 10	5 to 6	2·00 to 2·5	1·70 to 2·22	1·30 to 1·62
5	3	8 „ 14	5 „ 9	1·60 „ 2·8	1·36 „ 2·38	1·04 „ 1·82
6	4	10 „ 16	6 „ 10	1·66 „ 2·66	1·41 „ 2·26	1·08 „ 1·73
7	4	12 „ 18	8 „ 11	1·72 „ 2·57	1·46 „ 2 18	1·115 „ 1·67
8	5	14 „ 18	9 „ 11	1·75 „ 2·25	1·49 „ 1·91	1·14 „ 1·46
9	6	14 „ 20	9 „ 12	1·555 „ 2·22	1·32 „ 1·89	1·01 „ 1·44
10	6	16 „ 22	10 „ 14	1·60 „ 2·20	1·36 „ 1·87	1·04 „ 1·43
11	7	16 „ 22	10 „ 14	1·45 „ 2·00	1·23 „ 1·70	0·94 „ 1·30
12	8	18 „ 22	11 „ 14	1·50 „ 1·833	1·275 „ 1·56	0·975 „ 1·20
14	9	18 „ 24	11 „ 15	1·28 „ 1·714	1·09 „ 1·46	0·832 „ 1·12
16	10	20 „ 26	12 „ 16	1·25 „ 1·625	1·06 „ 1·38	0·812 „ 1·06
18	11	22 „ 28	14 „ 18	1·22 „ 1·555	1·04 „ 1·32	0·795 „ 1·01
20	12	22 „ 28	14 „ 18	1·10 „ 1·40	0·936 „ 1·19	0·716 „ 0·91
22	14	24 „ 30	15 „ 19	1·09 „ 1·36	0·926 „ 1·16	0·709 „ 0·887
24	15	26 „ 32	16 „ 20	1·08 „ 1·33	0·92 „ 1·13	0·705 „ 0·866
26	16	26 „ 32	16 „ 20	1·00 „ 1·23	0·85 „ 1·045	0·65 „ 0·800
30	19	30 „ 34	19 „ 21	1·00 „ 1·13	0·85 „ 0·965	0·65 „ 0·737

Pitch in the several Rows. — The pitch given by theory in the several rows of rivets will of course be subject to some modifications in practice. It is evident that there is a limit to the closeness with which two rivets may be brought together. This limit it is difficult to fix exactly, but it may be taken at $2\frac{1}{2}$ diameters. The extent beyond which the pitch should not be widened is yet more doubtful, except in the case of water-tight joints, as in ships, or steam-tight joints, as in boilers. For these it may be fixed at $4\frac{1}{2}$ and 4 diameters

respectively Lastly, it will of course be necessary to make the pitch vary in such a manner as will involve the addition or subtraction of an integral number of rivets.

Calculation for a Joint of Maximum Strength.—We will now give a single example of the calculation for an actual joint; and we will take the case of a plate which is not weakened anywhere outside the joint, and in which the joint is therefore to be as strong as possible. We shall assume the rivets to have the same diameter throughout, and shall follow the method developed in Section III.: first designing the joint as if the width of the plate was to remain constant, and then showing how to reduce this width towards the end of each plate. The joint as thus designed is shown in Figs. 6 and 7, Plate 28.

The particulars and dimensions of the joint, the latter in millimetres throughout, are as follows:—Iron plate, punched; width $L = 520$, thickness e of plate $A = 15$, thickness e' of plate $B = 21$, $\phi = \frac{21}{15} = 1 \cdot 4$, $C = \frac{1}{15}$, diameter of rivet $d = 20$. Hence

$$\frac{L}{d} = 26, \quad \frac{L}{d}\phi = 36 \cdot 4, \quad \phi + Cd = 2 \cdot 73, \quad \frac{Cd}{\phi + Cd} = 0 \cdot 488, \quad \frac{Cd^2}{\phi} = 19 \cdot 1.$$

With one rivet in the first row the greatest possible proportion of strength is

$$\rho = 1 - N_1 \frac{d}{L} = \frac{25}{26} = 0 \cdot 96;$$

and we must have

$$\frac{\frac{L}{d} - N_1}{Cd} = 18 \cdot 7 \leqq \Sigma_1^n N \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (II.)$$

The riveting of the successive rows will be regulated by the formulæ

$$N_m \leqq N_1 + Cd\Sigma_1^{m-1} N \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (I.)$$

up to the row m', for which we find

$$\frac{\frac{L}{d}\phi - N_1(\phi + Cd)}{Cd(1 + \phi + Cd)} = 6 \cdot 8 \leqq \Sigma_1^{m'-1} N \quad . \quad . \quad . \quad . \quad (IV.).$$

For the row m' and all beyond it, we follow the formula

$$N_m \leqq \frac{\frac{L}{d}\phi - Cd\Sigma_1^{m-1} N}{\phi + Cd} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (III.).$$

Hence we easily deduce the following Table of calculations:—

Calculation for Number of Rivets (Fig. 6, Plate 28).

No. of Row.	1	2	3	4	5	Remarks.
	N_m Rivets per row.	CdN_m	$N_1 + Cd\Sigma_1^{m-1}N \geqq N_m$	$\frac{Cd}{\phi + Cd}N_m$	$\frac{\frac{L}{d}\phi - Cd\Sigma_1^{m-1}N}{\phi + Cd} \geqq N_m$	
1	1	1·33	1	0·488	$\frac{\frac{L}{d}\phi}{\phi + Cd} = 13·3$	
2	2	2·67	2·33	0·976	12·812	
3	4	5·34	5·00	1·952	11·836	$\Sigma_1^3 N > 6·8$
4	9	..	..	4·390	9·884	
5	3	..	..	..	5·494	
$\Sigma_1^5 N = 19 > 18·7$						

In this Table each figure in column 3 is obtained by adding together the figures in columns 2 and 3 of the row above. Each figure in column 5 is obtained by subtracting the figure in column 4 from that in column 5 of the row above.

The reduction in width towards the end of the plates will be calculated by taking the width L'_m, so as to have up to the row m'

$$L'_m \geqq \frac{Cd^2}{\phi}\Sigma_1{}^m N + N_m d \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3b)$$

and then the width L_m, so as to have from the row m' inclusive up to n,

$$L_m \geqq L_1 - N_1 d + N_m d - Cd^2\Sigma_1^{m-1}N \quad . \quad . \quad . \quad (1b)$$

Hence these widths are given by the following Table;—

Calculation for Widths of Plates (Fig. 7, Plate 28).

	1	2	3	4	5	6
No. of Row.	$\Sigma_1^m N$ Total No. of Rivets.	$\frac{Cd^2}{\phi}\Sigma_1^m N$	$N_m d$	$\frac{Cd^2}{\phi}\Sigma_1^m N + N_m d$ (minimum for width L'_m of plate B).	$Cd^2\Sigma_1^{m-1}N$	$L_1 - N_1 d + N_m d - Cd^2\Sigma_1^{m-1}N$ (minimum for width L_m of plate A)
				Millimetres.		Millimetres.
1	1	19·1	20	39·1	..	$L_1 - N_1 d = 500$
2	3	57·3	40	97·3	..	..
3	7	133·7	80	213·7	..	..
4	16	305	180	..	187	493
5	19	362	60	..	426	134

Here column 4 is formed by adding together the numbers in columns 2 and 3. Column 5 is formed by multiplying the numbers of the row above in column 2 by ϕ. Column 6 is formed from columns 3 and 5.

From these calculations the design of the joint is determined, as finally given in Fig. 7, Plate 28.

VI. Various Applications of the Theory.

Riveting of a Joint with a given Proportion of Strength.—As already mentioned, when a plate is weakened away from a joint, either by holes cut in it or by the attachment of some other piece, it is useless to give to the joint a higher proportion of strength than corresponds to the weakened section. This proportion of strength being given, it is easy to calculate the elements of the joint accordingly. As an example we may calculate the joint, Fig. 8, Plate 28, of an iron deck-plate 800 mm. wide ($31\frac{1}{2}$ in.) and 12 mm. thick ($\frac{1}{2}$ in.), attached to the beams by a row of 5 rivets 20 mm. diameter (0·8 in.) and pitched at 8 diameters. The strength of the plate, at its attachment to the beams, is reduced in the ratio of 8 to 7, or to 0·875. We will take a slightly higher figure, 0·885, for the proportion of strength of the joint. We will assume the holes to be punched, the joint to be a butt-joint with one cover, and the rivets to be from 18 to 22 mm. diameter.

We shall then have $L = 800$, $e = 12$, $C = \frac{1}{12}$. Should we take the thickness of the cover the same as that of the plate, and assume two rows of rivets 22 mm. diameter on each side, we should only have, by (VII′.) p. 182,

$$\rho = 1 - \frac{1}{1 + \frac{2 \times 22}{12}} = \frac{11}{14} = 0 \cdot 785.$$

With a cover thicker than the plate, and with two rows of rivets, the greatest possible proportion of strength is given (Case 1 *b*, p. 179) by $\rho = 1 - \frac{1}{(1+Cd)^2}$. Taking rivets of 22 mm. diameter, the greatest possible value of ρ is $\frac{7}{8}$, in which case

$$N_1 = \frac{L}{d} \times \frac{1}{(1 + Cd)^2} = \frac{800}{22} \times \frac{1}{(2 \cdot 83)^2} = 4 \cdot 55.$$

This is a fractional number, which is inadmissible; and if we put five rivets in the first row, the strength will be insufficient. We must therefore adopt three rows of rivets. We shall then have, with a cover 12 mm. thick, by formula (VII′.), page 182,

$$\rho \leqq 1 - \frac{1}{(2 + Cd)(1 + Cd) - 1}$$

With rivets of 20 mm. diameter this value would be greater than 0·885, but we should have an inadmissible fractional value for N_1. If we take 22 mm. as the diameter, we shall have

$$N_1 \geqq 36 \cdot 4 \times \frac{1}{3 \cdot 83 \times 2 \cdot 83 - 1}, \text{ or } N_1 \geqq 3 \cdot 7.$$

If we take four rivets for the first row, $N_1 = 4$, and we must have

$$N_2 \leqq 4 \times 2 \cdot 83, \text{ or } N_2 \leqq 11 \cdot 32.$$

$$N_2 \geqq \frac{(36 \cdot 4 - 4 \times 2 \cdot 83)\, 2 \cdot 83}{1 \cdot 83 \times 3 \cdot 83}, \text{ or } N_2 \geqq 10 \cdot 1.$$

If we then take $N_1 = N_3 = 4$, and $N_2 = 11$, we shall have

for proportion of strength, $\rho = 1 - \frac{4 \times 22}{800} = 0 \cdot 890$

for relative pitch, $E_1 = E_3 = 9 \cdot 1$, $E_2 = 3 \cdot 3$.

If the joint must be water-tight, as in the case of a water-tight deck, the pitch of 9 diameters in row 3 is inadmissible. We must therefore use a cover thicker than 12 mm., but must still retain three rows of rivets. The calculation will then be as follows, following the formulæ of page 179, Case 1 (*a*). We have $L = 800$, $e = 12$, $C = \frac{1}{12}$, $d = 20$; whence $\frac{L}{d} = 40$, $Cd = \frac{5}{3}$. We wish to have

$\rho \geqq 0 \cdot 880$; whence $N_1 \leqq \frac{L}{d} \times 0 \cdot 120$, or $N_1 \leqq 4 \cdot 8$.

If then we take $N_1 = 4$, we have

$$\Sigma_1^n N \geqq \frac{\frac{L}{d} - N_1}{Cd}, \text{ or } \Sigma_1^n N \geqq 21 \cdot 6,$$

and we deduce the following Table of calculations:—

No. of row.	N_m Rivets per row.	$Cd\ N_m$	$N_1 + Cd\ \Sigma_1^{m-1} N \geqq N_m$	E_m Relative Pitch.
1	4	6·66	4	10
2	8	13·32	10·66	5
3	10	..	23·98	4
$\Sigma_1^3 N = 22 > 21·6$				

We shall then have $\rho = 1 - \frac{4 \times 20}{800} = 0·900$;

and by formula (V.), p. 179, we must take $\phi \geqq \frac{Cd\Sigma_1^n N}{\frac{L}{d} - N_n}$, or $\phi \geqq 1·222$.

The thickness of the cover-plate will be given by

$$e' \geqq 1·222 \times 12, \text{ or } e' \geqq 15.$$

Calculation for the Joints of a Keelson, to which are attached water-tight frame-plates, Fig. 9, Plate 28.—At the attachment of the frame-plates, the rivets must be spaced at $4\frac{1}{2}$ diameters at furthest: hence the strength of the keelson plate is reduced in the ratio of 45 to 35, or to 0·777. It is therefore needless to give the joint in the keelson a greater proportion of strength than 0·78. A steel plate 12 mm. thick ($\frac{1}{2}$ in.), having rivets 22 mm. diameter ($\frac{7}{8}$ in.), and with either two covers single-riveted, or one cover of the double thickness double-riveted, would only give a proportion of strength

$$\rho = 1 - \frac{1}{1 + \frac{2 \times 0·65 \times 22}{12}} = 0·705.$$

A double cover with two rows of rivets will allow us to take (writing 2 C for C in the latter of the two formulæ VII′, p. 182, to allow for the double cover)

$$E_1 = E_2 \leqq 1 + 4\ Cd, \quad \text{or } E_1 = E_2 \leqq 5·72.$$

Hence a pitch comprised between 5·72 diameters and $\frac{1}{1-0·78} =$ 4·55 diameters, will give a proportion of strength above the required limit.

Weakening of Plates at Points of Attachment.—Since the weakening of plates by their attachment to other pieces limits the strength which it is possible to give to them, it is most desirable to diminish this weakening as far as possible; especially in the case of important connecting pieces, such as deck-plates, shell-plates, keelsons, &c. The evil of this weakening has a special importance in the case of water-tight attachments, where from the narrowness of the pitch the proportion of strength is necessarily reduced to about 0·78.

It is possible largely to reduce this loss of strength by the employment of cover-plates or strengthening plates, secured by suitable riveting to the two pieces at their point of attachment. We will first indicate the general mode of proportioning these strengthening plates and their rivets, and we will afterwards take an example from shipwork, namely the calculation of the cover-plates, or strengthening plates, placed at the junction of the shell-plates and the water-tight frames.

Let A, Figs. 10 and 11, Plate 29, be a plate of width L, which is weakened by the rivet holes at the attachment of a transverse angle-iron or T iron B. Then the strengthening plate C is to be riveted to the plate at the position of attachment, so as to form a joint having a given proportion of strength.

It is clear that the joint will be symmetrical on both sides of the row M, Fig. 10, or of the rows M and M + 1, Fig. 11, which are formed by the rivets making the attachment. The total number of rows uniting the cover to the plate will therefore be $n = 2\ \mathrm{M} - 1$, or $n = 2\ \mathrm{M}$ respectively. Secondly, the strength of the joint cannot be greater than the resistance $\mathrm{R}_1 = a_1$ of the plate A along the row of rivets 1 or n, at the outside of the cover. Thus, assuming at first that the thickness of the cover is too great to allow it to break anywhere, we see, as in page 169, that for every possible mode of fracture of plate A the resistance must be greater than R_1, and that this gives the condition—

$$a_m + \Sigma_1^{m-1}\, r \geqq a_1.$$

Hence if the width is the same, and the rivets equal throughout, we shall have

$$\mathrm{N}_m \leqq \mathrm{N}_1 + \mathrm{C}d\Sigma_1^{m-1}\mathrm{N} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (\mathrm{I.}).$$

This is the same formula as that for a single cover-plate in an ordinary joint. Since the joint cannot give way by the shearing of all the rivets, condition (II.) is in this case superfluous.

Again, as in page 170, we shall easily establish the supplementary condition necessary to prevent rupture of the cover. Since the plate A is not divided, this cover cannot give way unless plate A gives way also. Hence, the joint being symmetrical, we need only consider the case where A gives way along some row, m, of one of the two halves of the joint, as in Fig. 12, Plate 29. The cover C may then give way either at row m, or at row $m - 1$, or at row $m + 1$, without any shearing of the rivets; or it may give way along some other row p, and the rivets between the rows m and p may be sheared. It will be needless to consider the case where p is in the opposite half of the joint from m; since the cover C would sooner give way along the symmetrical row in the other half, where its tensile resistance is the same, and for which the number of rivets to be sheared would be less. Assuming m and p to be in the same half of the joint, we shall find, as in page 171, that if the resistance for any of the above modes of rupture is to be equal to or greater than R_1, it is sufficient to have for any row between 1 and M

$$b_m \geqq \Sigma_1^m r\,;$$

or, if the rivets are equal throughout, by formula (3 b), p. 176,

$$\left(\frac{L'_m}{d} - N_m\right)\phi \geqq C d \Sigma_1^m N \quad . \quad . \quad . \quad . \quad . \quad \text{(III.)}$$

If we suppose that the cover is of constant width L, the pitch will decrease from row 1 to row M, in accordance with formula (I.). Hence if formula (III.) is satisfied for row M, it will be satisfied *a fortiori* for all the other rows, since N_m and $\Sigma_1^m N$ both decrease.

Consequently, if the proportion of strength ρ is given, N_1 will be determined by the formula

$$N_1 \leqq \frac{L}{d}(1 - \rho).$$

The pitch in the successive rows is then regulated by formula (I.),

$$N_m \leqq N_1 + C d \Sigma_1^{m-1} N.$$

The number of rows is fixed by the condition,

$$\left(\frac{L'}{d} - N_M\right)\phi \geqq Cd\Sigma_1^M N,$$

where the value of N_M is given, being the number of rivets in the attachment of the frame.

Finally we may determine the diminution in width to be given to the cover, by applying formula (III.), or

$$L'_m \geqq N_m d + \frac{Cd^2}{\phi}\Sigma_1^m N.$$

The other half of the joint will of course be identical in its design.

Strengthening-plates for the outside Strakes of Shell Plating, Fig. 13, Plate 29.—The strakes of the shell plating are evidently weakened, wherever they are attached to the water-tight frames of the vessel, to the same extent as the keelson last considered, that is to the ratio $\frac{7}{9}$. On the other hand the riveting in the other frames has a pitch of about 8 diameters, and the reduction in strength is therefore to $\frac{7}{8}$ only. The plates themselves are supposed to break joint in such a way that the mean proportion of strength in the skin between any two frames is greater than $\frac{7}{8}$.

It is therefore desirable to give to the outer plating at its junction with the water-tight frames a proportion of strength not less than $\frac{7}{8}$. For this purpose the filling plate, which must be inserted between the outside strake and the frame, is often extended to reach to the frame on each side. In other cases it is considered sufficient to make this plate wide enough to insert a second row of rivets; but this is far from obtaining the desired result. The result may be obtained however, with a great economy over the extended filling plates mentioned above, if we employ as filling plates strengthening plates whose riveting is proportioned according to the theory here developed.

Consider an inside strake A, Fig. 13, Plate 29, and an adjoining outside strake B. The mean proportion of strength of the two strakes together is now $\frac{7}{9}$, or 0·777, and it is required to make it $\frac{7}{8}$, or 0·875. Since the inside strake A must still retain the proportion $\rho_1 = 0·777$,

we must increase the proportion ρ_2 for the outside strake B, so as to have

$$\frac{\rho_1 + \rho_2}{2} = 0 \cdot 875 ;$$

whence $\rho_2 = 2 \times 0 \cdot 875 - 0 \cdot 777 = 0 \cdot 973 ;$

we must then take $\mathrm{N}_1 \leqq \frac{\mathrm{L}}{d} (1 - \rho_2).$

The riveting of the successive rows, the number of rows, &c., will be fixed by the formulæ given in the last example.

Riveting of Corner Angle-irons.—We will here consider the case of a plate A, Fig. 14, Plate 29, which is to be united to another plate B, crossing it at right angles, by an angle-iron C. The riveting of plate A to the angle-iron must be fixed as in the case of a joint with one cover; or, if there are two angle-irons, Fig. 15, as in the case of a joint with two covers. Supposing this riveting settled, it is clear that the rivets which unite the other flange of the angle-iron to plate B must have a total resistance to tension equal to the resistance of the joint uniting A and C. If this joint is one of equal resistance, its strength per unit length will be the total resistance to shearing of all the rivets in that length. If then we assume for simplicity that the tensile resistance of the rivets is the same as the shearing resistance; and if we denote by d the diameter of the rivets in plate A, and by N_1 N_2 the number in each of the two rows, and denote by d' N_1' N_2' the same elements for plate B; then we must have

$$d^2 (\mathrm{N}_1 + \mathrm{N}_2) = d'^2 (\mathrm{N}_1' + \mathrm{N}_2').$$

Or if we substitute for the number of rivets the mean relative pitch E, we shall have

$$d \left(\frac{1}{\mathrm{E}_1} + \frac{1}{\mathrm{E}_2} \right) = d' \left(\frac{1}{\mathrm{E}'_1} + \frac{1}{\mathrm{E}'_2} \right) . \quad . \quad . \quad . \quad (7).$$

It is clear that the same relation will hold where there are two angle-irons at the junction.

If the joint between A and C is not exactly of equal resistance, we must take as its strength the resistance of the thinner plate along the first row of rivets. The condition just given will then be more

than sufficient, and the attachment of the angle-iron to plate B will be stronger than that to plate A.

Hence, if we wish to give the greatest possible strength to a joint of this kind, we must first settle the riveting of plate A, and must then deduce by formula (7) the riveting of plate B. But if, as is often the case, the pitch on plate B must not be below a certain limit, for fear of weakening the plate, we must deduce by formula (7) the number of rivets per unit length for plate A; and then divide these into one or two rows as may be advisable, so as to satisfy the general rules of the theory.

Influence of Corrosion on the Strength of Riveted Joints.—When plates are exposed to a considerable and regular corrosion, as on the inside of boilers and the outside of ships, their strength and that of their joints gradually diminishes; and it is the strength after corrosion, when fracture is most likely to take place, which is the most important. It is therefore desirable to examine this point.

Let us assume for simplicity that the plate is corroded regularly on one face only, and that it is butt-jointed with one cover, the corrosion being on the opposite face. Let the thickness be thus reduced to a fraction m of its original thickness. The strength of the plates along the row of rivets will then be reduced in the same proportion, whilst the strength of the rivets will be unaltered. Now if the joint has been designed on the basis of the strength of the plate along row 1, its proportion of strength will remain the same after corrosion. On the other hand, if the joint was originally of equal resistance, the strength of the rivets after corrosion will be in excess. Hence if we wish the joint to be of equal resistance after corrosion, that is when the plate is reduced in the proportion m to 1, we have only to design the joint originally with this view; that is to say, instead of using the value R for the tensile strength of the plate, we must use the value mR. The plate will then be stronger than the rivets at first, but this excess of strength will be destroyed by the corrosion.

Reduction in Width.—It often happens, in ship-work especially,

that the actual strength of a joint, which is always less than that of the solid plate, falls of necessity much below this superior limit; so that, outside the joint, the plates have a strength, and therefore a weight, much beyond what is necessary. For this reason it has been proposed to use, for boilers, plates with thickened edges (*see* Proceedings Inst. Mech. E. 1872, p. 71); and in such cases this appears the only possible solution, although it unfortunately presents great practical difficulties. For plates which are not to be water-tight it is an obvious remedy to reduce the width, by cutting out parts or otherwise, everywhere except at the joint. Such reductions in width have become general in ship-work, but they are not always proportioned in a rational manner. Taking only the ordinary case, in which a plate is subjected to no stresses except those of tension, it is clear that the reduction in width should be such, that the ratio of the reduced to the full width is equal to the proportion of strength in the joint. The latter may be determined by the rules laid down in this paper; and the proper reduction of width can thus be fixed without difficulty.

RESULTS OF EXPERIMENTS ON RIVETED JOINTS MADE FOR THE INSTITUTION OF MECHANICAL ENGINEERS.

By Prof. ALEX. B. W. KENNEDY, of London.

The Author has been asked by the Council and the Committee on Riveting to place before the members of the Institution, in the form of a paper, a statement of the general results of a series of experiments bearing upon the strength of Riveted Joints, which have been made by him for the Committee. The form which the experiments have taken was determined on after much discussion by this Committee, and will be presently described. The material used throughout both for plates and rivets was "mild steel" of very uniform quality, made by the Landore Steel Company. The machining and other preparation of most of the specimens, and the whole of the riveting up, was done by Mr. William Boyd, at his works at Wallsend. The actual testing of Series I. to VII. was done upon the testing machine in the author's laboratory at University College, and under his own immediate superintendence. The specimens in Series VIII., which were too large for this machine, were tested at Barrow in the machine belonging to the Barrow Hæmatite Steel Company; who kindly allowed the Author to supervise the experiments, so that they might be conducted throughout similarly to the former ones. It may perhaps be mentioned here that the supply of the material from Landore, the long and troublesome preparation of the specimens by Mr. Boyd, as well as the use of the testing machine at Barrow, have been entirely without expense to the Institution; and the Author has had much pleasure in putting his services at the disposal of the Committee in the same way.

It ought also to be added that the Author, having been asked simply to make a statement of his own results, has not of course made any attempt to compare these results with those of others. So

far as the business of the Committee is concerned, the work of making any such comparison has lain happily in the much abler hands of Prof. W. C. Unwin, whose most valuable comparative Tables and Report are already in the hands of members.*

In carrying out the experiments presently to be described, it was thought advisable that a material of the greatest attainable uniformity should be used; and for this purpose Landore "S. S." steel was employed for the plates, and a still milder quality for the rivets. It was next thought important that a careful preliminary investigation should be made of the actual properties of these materials, *i.e.* the tenacity and extensibility of the plates and rivet steel (Experiments Series I. to III.), and the resistance of the latter to shearing (Series IV.): the effect of punching and drilling upon the plates, both in narrow and broad specimens, was also investigated, and incidentally also the influence of annealing upon the plates (Series V. and V_A.). These matters being determined, experiments upon actual joints were made. These include three series, Nos. VI., VII., and VIII. The first, Series VI., consists of twelve joints, each with two rivets, three different diameters of rivets being used, and with each diameter two proportions of plate and rivet area. Series VII. consisted of six joints, each with three rivets, of the same diameter, but differently proportioned as to pitch &c. The results obtained from these were used in the preparation of the last Series VIII., consisting of eighteen joints, each having seven rivets, and divided into six sets, each of three similarly proportioned joints. All the joints in these three series were single-riveted lap-joints.

Tenacity of Plates.—Tables I. to VII., appended to this paper, give the detailed results of the preliminary experiments above referred to, so far as they relate to the tenacity of the plates. Tables I. and IV., both arranged on the same plan, give the results of the usual tensile tests of twenty-eight pieces of plate, varying from $\frac{1}{4}$ in. to $\frac{1}{2}$ in. in thickness. The difference between the specimens of Series I. and II. (Tables I. and IV. respectively) lies only in the method of holding them while being tested, Series I. being pulled from pins, Series II.

* This Report, as revised, is included in the present No. of Proceedings, p. 301.

being held in wedge grips. It may be said here at once that the method of holding does not seem, within the limits of these experiments, to have made any appreciable difference in the strength of the pieces. All these specimens had a length for testing of 10 in., and both $\frac{1}{4}$ in. and $\frac{3}{8}$ in. were tested in different breadths. The $\frac{1}{4}$ in. plates, when tested $1\frac{5}{8}$ in. wide, gave an average tenacity of 30·35 tons per square inch, and, when tested 4 in. wide, of 30·07 tons per sq. in. The mean tenacity* of the whole was 30·21 tons per sq. in., with 21·2 per cent. extension in 10 in. The $\frac{3}{8}$ in. plate was decidedly milder, having an average tenacity of 28·59 tons per sq. in., and an extension of 24·8 per cent. in 10 in. Tested 2 in. wide, its average tenacity was 28·58 tons per sq. in., and, tested $3\frac{1}{2}$ in. wide, 28·59 tons per sq. in. It appears therefore that within the limits mentioned no difference is made by alterations of width, so that the width which is most convenient in any particular case may be used with equal certainty of trustworthy results—a fact sometimes worth remembering. The $\frac{1}{2}$ in. plate was tested only in one width, $2\frac{3}{4}$ in., and had a mean tenacity of 28·96 tons per sq. in., and an ultimate extension of 24·8 per cent. in 10 in. It will be seen therefore that the material tested was a very uniform quality of ductile "ingot iron," the thin plates being, as was to be expected, and as was found throughout, somewhat the hardest. The author is informed that the proportion of carbon in these plates, according to analysis at Landore, was about 0·18 per cent.

Tables II. and V., which correspond to each other for Series I. and II., give the results of detailed observations as to the elasticity of the material. Each specimen, before being tested, was scribed across at $\frac{1}{2}$ in. distances through its whole length. After fracture the extension was measured, first on the whole 10 in. in the ordinary way, next on the $2\frac{1}{2}$ in. (or quarter length), within which the fracture had actually occurred, and lastly (by subtraction) on the remaining $7\frac{1}{2}$ in. In Tables II. and V. all these measurements are given. The extension on the $2\frac{1}{2}$ in. nearest to and including the fracture covers practically all of what is usually called the "local extension"; and

* These averages are given in Table VII.

therefore the extension on the remaining part of the length ($7\frac{1}{2}$ in.) may be taken as representing the *real* ultimate extension of the material, or the extension which would be obtained in a test bar so long that the small additional extension close to the fracture did not sensibly affect the whole stretch. In the $\frac{1}{4}$ in. plate (taking the mean of both series) the real ultimate extension is 16·1 per cent., and in the softer $\frac{3}{8}$ in. plate 18·5 per cent., the $\frac{1}{2}$ in. plate giving 17·7 per cent. Somewhat contrary to the Author's expectation, the percentages of extension in the $7\frac{1}{2}$ in. are distinctly less uniform than those in the whole 10 in., the local extension appearing more or less sensibly to affect the whole of that length. The figures in the Tables emphasise very strongly the well-known necessity for specifying always the length of the piece on which a given percentage of ultimate elongation has taken place. The extension on the $2\frac{1}{2}$ in. is in one case as high as 53 per cent., (No. 271–1, Table II.) and the mean of the $\frac{3}{8}$ in. plates of Series I. is 48·2 per cent.; while the mean extension on 10 in. is only 27 per cent., and on the $7\frac{1}{2}$ in. 19·8 per cent.

Elasticity.—Tables III. and VI. contain the results (for Series I. and II. respectively) of very detailed observations made as to the elasticity of the material under test. A simple apparatus was attached to the specimen, which measured the extension, permanent or temporary, between points 10 in. apart. This apparatus * neither formed part of, nor even touched in any way, the testing machine itself, so that its indications were entirely independent of any strains in the machine, or in any part of the test piece except that lying between the marked points. It was capable of indicating, with very fair certainty, $\frac{1}{10000}$ of an inch. By the use of this apparatus, and the subsequent plotting out of the observations in the form of diagrams, the results given in the Tables were obtained—results which appear to possess considerable interest.

By sufficiently careful observations it is possible to distinguish *three* distinctly marked points in connection with what might be

* A later apparatus, similar in principle, is illustrated in *The Engineer* of Feb. 25, 1881.

called the "elastic life" of the material. The first of these is the point at which permanent set begins to be visible. This occurred always at comparatively low loads, far below the point usually called the limit of elasticity. The column marked I gives the load at which permanent set actually began, so far as was visible with the apparatus used. *From this it went on increasing*, although very slowly, as the load was increased. Fig. 1, Plate 30, shows, in illustration of this matter, the observations on a 10 in. length of No. 272–2 (Table III.), a specimen of average tenacity and elasticity, in which set began extremely early. Here the set curve distinctly commences at a load of 8·21 tons per sq. in. Out of twenty-four specimens for which this point was determined, it occurred in five cases at less than 9 tons per sq. in.; and for the whole of the $\frac{1}{4}$ and $\frac{3}{8}$ in. plates it averaged just 40 per cent. of the breaking load, and about 60 per cent. of the load usually called the limit of elasticity.

It will be seen from the magnified curve of extensions in Fig. 1, Plate 30, that up to a certain point the observed extensions lie all upon one straight line with very great exactness; after that point (which in the diagram is reached at 14·78 tons per sq. in.) the line begins to curve upwards. This fact was equally distinct in all the other specimens. This second point, the load at which the extension ceases to be uniform, is noted in column II. of Tables III. and VI., having in each case been determined by plotting the observations on a diagram. In two instances (268–2 and 268–3) this point sensibly coincides with the point at which permanent set first occurs; in all the others it is very much above it.* The average set, or permanent extension, on removal of load, at the point when uniform extension ends, is about $\frac{4}{10000}$ in. in the length of 10 in.; it varies from $\frac{1}{10000}$ to $\frac{11}{10000}$ in those cases in which it occurs. There was

* The very low point of commencement of permanent set is not at all peculiar to mild steel, but is probably more or less characteristic of all ductile materials. In five bars of a very fine quality of wrought iron, recently examined by the author, the extension ceased to be uniform at 14·28 tons per sq. in. in the average, while permanent set was visible at, and steadily increased from, a load of 7·28 tons per sq. in. in the average. In one case the commencement of set occurred distinctly as early as 3·57 tons per sq. in.

no case in which set did not begin either at or before the point at which uniform extension ended. The average *total* extension (in 10 in.), at the point where it ceased to be uniform, was 0·0109 in., or say $\frac{11}{1000}$ of an inch. The average permanent extension or *set* at this point, therefore, was about $\frac{1}{25}$ of the total extension at the same point.

Neither of the two points mentioned—namely the points where permanent set begins and where uniform extension ends—can be determined without such special and tedious measurements of small extensions as will enable such curves as those of Fig. 1, Plate 30, to be drawn out. Neither therefore can be noticed in ordinary testing; and consequently neither of them is the point commonly fixed as the limit of elasticity. If the limit of elasticity be the point at which permanent elongation commences—as it is usually defined to be in books—then column I. of the Tables represents it. If it be the point where the extension ceases to be proportional to the stress, (as, for instance, it is taken in Mr. Kirkaldy's valuable experiments on 100-inch bars) then it is given in column II. Attention is drawn to this matter, not to find fault with established usage, but simply to point out that the real limit of elasticity of a material is in most cases passed considerably before the only point which can be observed in ordinary testing is reached. What is called commercially the limit of elasticity will be found to be a point very considerably higher than the limit which corresponds to any of the usual scientific definitions. It would doubtless be convenient if some different name could be found for one or the other point.

The load corresponding to what is ordinarily called the limit of elasticity is given in column III. of the Tables. As this is certainly the most remarkable point in the life of the material, and as the phenomena accompanying it do not appear to be thoroughly known, it may be worth while describing them somewhat minutely; for which purpose it is necessary to say a few words as to the apparatus employed for making the tests. The testing machine used was one upon Mr. Kirkaldy's principle,* the load being

* Detailed illustrations of the machine were published in "Engineering" for 26th Sept., 1879.

applied by a pump and ram, and the stress in the piece balanced and measured by a moveable weight hanging upon a steelyard. So long as the steelyard is floating (or its end free between the two pins which limit its motion), the load upon it (multiplied by the proper factor for leverage) is exactly equal to the stress in the piece under test. During the early part of the test the steelyard is kept thus always floating, the increased load applied by the continued pumping being continuously balanced by the movement of the weight outwards upon the steelyard. This floating of the steelyard continues until long after the loads in column II. are passed, and then it *suddenly* ceases, and without any change in the rate of increase of load, often without the least visible warning, the steelyard drops down and rests upon the pin below it. Up to this point the material has been able to balance each increase of load directly it was applied, with only such increase of length (always very small) as the load itself at once caused. At this point however some structural change appears to occur, a change which is perhaps best described by the phrase "breaking down." What happens, at least so far as extension is concerned, is shown distinctly by the actual curve of extensions at the right-hand side in Fig. 1, Plate 30. The first part of the length of this line would be simply a repetition to actual scale of the magnified extension line above it, and is too close to the base line to be shown. At the point where permanent set appears to begin (8·21 tons per sq. in.), the total extension was 6·6 thousandths of an inch. It increased uniformly till the stress was 14·78 tons per sq. in., and was then 12·2 thousandths, of which 1·2 thousandths was permanent set. The extension then ceased to be uniform, and had increased somewhat rapidly to 33 thousandths, when, at 18·23 tons per sq. in., the resistance of the piece suddenly seemed to collapse or break down, and the steelyard dropped in the way described. So far as appearances went, the piece might have continued to balance say 18·0 tons per sq. in., or even more, for an unlimited time, with the corresponding extension of about 30 thousandths. But when once the breakdown occurred, the material not only would no longer balance 18·23 tons, but could not even balance a much smaller load. In such a case it will be found on trial (by reducing the load gradually and finding the point where the steelyard naturally lifts

again of itself) that with the full extension the piece will only balance about 80 per cent. of the load that has been already upon it, or in this case about 15 tons per sq. in. On leaving the weight in the position corresponding to 18·23 tons per sq. in., the position in which it was when the steelyard dropped, and continuing to pump, it was found that the extension had increased to nearly 200 thousandths, or 0·2 in., before the steelyard lifted again, *i.e.* before the material was able for the first time really to balance the stress of 18·23 tons per sq. in. This sudden increase of extension without increase of load is shown by the vertical part of the actual extension curve in Fig. 1, Plate 30. After this point the extension continues to increase faster than the stress, and the curve assumes the well-known appearance shown. During nearly all this final extension the steelyard can often again be kept floating, if proper care be taken.

Taking averages from the observations, it may be said (in round numbers) that, if the extension of the piece where uniform extension ended be called 1, the extension at the point where the material broke down would be 4, and would have to increase to 17 under the same load before the piece could take any higher load.

If the limit of elasticity be taken as the point at which permanent extension begins, it will (for this material) be at only 38 per cent. of the breaking load. If it be taken as the latest point where strain and stress seem to be proportionate, it will be at about 47 per cent. of the breaking load. If lastly it be taken (as it practically is always for commercial purposes) as the point where the material "breaks down," —the point given in column III. of the Tables,—it is not reached until at 68 per cent. of the breaking load. The average in each case is taken on the 24 (out of 28) specimens on which complete measurements were made. The figures in brackets, put in the Tables for comparison, are not included in the computation of averages.

In any further reference to limit of elasticity in this paper, it is the point where the material breaks down that will be referred to, unless a special statement is made to the contrary.

Tables III. and VI. further give some of the most important ratios in detail; and in the last column give the modulus of elasticity of the material, where it was determined. The figures in the

column headed $\Delta\epsilon$ are however, the author believes, practically more convenient than the modulus of elasticity. Here $\Delta\epsilon$ may be called the *specific extension* of the material. It is the actual average extension of the specimen in a length of 10 in., measured in thousandths of an inch, for a stress of 1000 lbs. per sq. in. To obtain the actual extension of any piece of the same material under any load, it is only necessary to multiply the specific extension (which as a small figure is easily remembered) by the load in thousands of pounds per sq. in., and by the length in inches, and to divide by 10. The quantity itself has been obtained by calculating the mean in each case of (generally) two or more series of observations of the extensions, up to some point as closely as possible approaching that given in column II. In most cases the average of the first series of observations made on a piece has not been taken into account, as those first observations frequently showed small discrepancies, due very probably to some initial strain in the bar or plate, which is removed by the first stretch.

The values of the modulus of elasticity E are obtained from those of the specific extension, the latter of course being the only quantity directly resulting from observation. Arithmetically it can easily be seen that E is equal to 10,000,000 divided by the specific extension. The mean values given for E are the values corresponding to the mean specific extensions, and are therefore slightly different from the arithmetical mean of the figures given in the columns for E.

A summary of the principal results of the first six Tables is given in Table VII., which does not require further mention.

Tenacity of Rivet Steel.—The results of the experiments on the tenacity of the rivet steel (Series III.) are given in Tables VIII. IX. and X., which are arranged precisely as those already examined. Three sizes of steel were tested, viz. $\frac{11}{16}$ in., $\frac{15}{16}$ in., and $1\frac{1}{16}$ in. diam., turned down to about 0·5 in., 0·6 and 0·8 in. respectively, and screwed at the ends. The three sizes give somewhat varying results, but the average of the nine specimens tested comes extremely near the average results obtained from the plates. The elastic limit was reached at 20·65

x

tons per sq. in. (in mean), or 71 per cent. of the mean breaking load, which was 29·12 tons per sq. in. The mean ultimate extension was 21·4 per cent. in 10 in.

From column I. of Table X. it will be seen that no permanent set could be detected below 15·6 tons per sq. in., in mean,—a very much higher average than with the plates. The limit of elasticity is also somewhat higher than before. The specific extension was very uniform, its mean value in thousandths of an inch being 0·326, which gives a mean value for the modulus of elasticity of 30,670,000 lbs. per sq. in.

Shearing Strength of Rivet Steel.—Table XI. gives the results of sixteen experiments on the shearing resistance of the rivet steel, of which the last Table gave the tenacity and other properties. All three sizes of bar were tested. The apparatus used in these experiments is shown in Figs. 2 and 3, Plate 30. The specimen S, after being turned, was fitted into a pair of rings R R, made from pieces cut off the ends of the $\frac{3}{8}$ in. specimens of Series II.; the edges of these rings being just touched with a file previously, to make sure of there being no burr, or absolutely sharp cutting edge. These rings were bedded in cast-iron blocks B B, enclosed in a bored chamber C, and pressed together between steel die faces in the testing machine. So far as the shearing edges were concerned, the piece under test was in this way brought as nearly as possible into the condition of the rivets, in the joints to be afterwards experimented on. Several specimens, including two which were removed for inspection before fracture actually occurred, lie on the table.

The load at which the specimens actually shore across varied very considerably in the different sizes. The $1\frac{1}{16}$ in. bar gave a mean resistance of 24·35 tons per sq. in., or 88·7 per cent. of its tensile resistance; for the $\frac{15}{16}$ in. bar these figures were 26·63 tons and 86·7 per cent., and for the $\frac{11}{16}$ in. bar 23·41 tons and 80·3 per cent. respectively. The mean of these quantities is 24·8 tons per sq. in., and 85·2 per cent. In some instances a point could be observed corresponding to the breakdown of the material in the tensile experiments; but it was not very distinct or very uniform.

Punching and Drilling.—The results of the experiments in series V. and V_A. are given in Tables XII. to XV. These experiments (*see* First Report, p. 363) had a three-fold object; (1) to examine the effect of drilling and punching holes in the material, (2) to find out how far such results were affected by the width of the specimen, and (3) to see if the strength of the punched holes was affected by the size of the die as compared with the punch. The second point is of special importance in enabling conclusions to be drawn, as to how far the results obtained from experiments on narrow joints may be safely applied to the broad joints of actual practice. Each series consisted of thirty-two specimens, sixteen of $\frac{1}{4}$ in. and sixteen of $\frac{3}{8}$ in. plate. Of each sixteen, eight had drilled and eight punched holes, half the latter being punched with a large and half with a small bolster The holes were all nominally 1 in. diam. and 2 in. pitch; and the specimens were arranged in sets of four, one of one, one of two, one of three, and one of four pitches in width, as suggested in the First Report, p. 363, and as shown in Plate 36, Fig. 17. None of the plates were annealed, but all drilled or punched by Mr. Boyd exactly as received. The natural tenacity of the plates of series V. was determined by cutting eight specimens from them and testing them in the usual way, the results being given in Table XIII. The $\frac{1}{4}$ in. plate had a mean tenacity of 34·41, and the $\frac{3}{8}$ in. plate of 31·45 tons per sq. in., both being therefore somewhat harder than the specimens previously tested.

The result of making a hole in a specimen is to localise the extension altogether to the immediate neighbourhood of the hole; and this virtual shortening of the length of the specimen is accompanied, in a ductile material, by a very considerable increase in its tenacity—that is in the tenacity of the remaining part of the material—unless the mode of formation of the hole has been such as to injure the material in any way. This is shown very distinctly in the experiments. The $\frac{1}{4}$ in. drilled plates, Table XII., have 10·7 per cent. and the $\frac{3}{8}$ in. 11·9 per cent., greater tenacity than the untouched plate. In the $\frac{1}{4}$ in. punched plate, in spite of the injury done by punching, there is still 1·2 per cent. greater tenacity than in the untouched plate. In the $\frac{3}{8}$ in. plate, perhaps on account of its

greater mildness, the punched plates have an excess of strength of as much as 8·4 per cent.

All the plates of series V. being somewhat harder than it had been intended to use, the experiments of series V_A were undertaken with plates of the original quality. This series also contained thirty-two specimens, arranged in Tables XIV. and XV. in precisely the same way as the former. The natural tenacity of the plate, as given in Table XV., is 29·0 tons per sq. in. for the $\frac{1}{4}$ in., and 28·87 tons per sq. in. for the $\frac{3}{8}$ in. plate. The effect of drilling, Table XIV., is practically the same as before; it gives 11·2 per cent. increase of resistance in the $\frac{1}{4}$ in., and 10·8 per cent. in the $\frac{3}{8}$ in. plate. The $\frac{3}{8}$ in. punched plates have in mean 5·8 per cent. of increase, and the $\frac{1}{4}$ in. punched plates 6·4 per cent.

It should be stated that in the case of the punched plates the diameter of the holes was measured on both sides of the plate, and the mean of the two diameters taken in calculating the amount of metal removed.

In two other matters these experiments give interesting results. First, the very considerable difference in diameter of bolster (amounting to $\frac{1}{16}$ in. in each case) has no definite effect in such thin plates as these, either one way or the other. In some cases the large and in some the small bolster gives apparently the better result; but the differences are so small as to be quite within the differences between individual plates, and only show that the effect of altering the bolster is excessively small.

In another matter the results have a still more practical interest, in view of past and future experiments. The specimens, as has been pointed out, varied in width from 2 in. to 8 in.; quite room enough for the effect of width—if there were any—to show itself. An examination of the results shows however that there is practically no difference worth mentioning between the narrow and the broad specimens. Comparing, for instance, the mean of all the sixteen 2 in. specimens with the mean of all the sixteen 6 in. specimens, it will be found that the former have 0·6 per cent. greater resistance. Comparing similarly the sixteen 2 in. with the sixteen 8 in. specimens, the difference is only 0·75 per cent. Such differences

are of course far within the differences between single plates. This very satisfactory identity of strength of the small and large specimens may arise in part from the way in which they were made; namely that the whole row of drilled or punched holes was first carried right across the plate, Fig. 17, Plate 36, and then afterwards the separate specimens were cut out of it. Thus the holes near the edges of the specimen were not, when they were made, near the edges of the plate, and any possible alteration of strength due to this cause was obviated. Considering how much more convenient it often is to experiment with small than with large specimens, it is satisfactory to know that (within certain limits at least), identical results can be obtained from both.

The real cause of the very marked increase of strength due to the drilling of holes in a ductile material has not as yet, the author believes, been pointed out. It is not however difficult to understand, when the actual fracture of the material is examined. The increase of strength due to the localisation of fracture at a section of the material not probably the weakest can go for very little indeed with a material so uniform as that here examined, and the cause must be sought elsewhere. In Figs. 4 to 7, Plate 31, are shown the forms taken by lines scribed originally parallel to each other on the specimens, at right angles to the direction of the pull. In Figs. 4 and 5, which show the fracture of two of the specimens tested for tenacity, will be noticed the familiar local contraction of breadth. The "flow" of the material is always such that the originally parallel scribed lines become concave towards the fracture, the curvature becoming greater and greater as the lines lie nearer and nearer the fracture. The inevitable consequence is that, before the material breaks, the stress in it is *not uniform* (as it is commonly assumed to be), but is much greater at the centre than at the sides. When the two fractured halves are brought together afterwards, they touch at the sides and are quite wide apart in the middle; as can be seen from Figs. 4 and 5. But in the specimens with holes in them, the flow is in some points exactly reversed. The greatest extension occurs of course along the centre lines of the holes; between the holes therefore the cross lines become convex to the fracture, and the curvature of the lines diminishes instead of increasing as the actual

fractured section is reached. From the straightness of the cross lines close to the fracture, in Fig. 6, it will be seen that the stress must have been as nearly as possible *uniformly* distributed over the metal between the holes. There can be little or no doubt that this is the real cause of the difference between the perforated and unperforated plates. The natural flow of a ductile material is such that the stress over the fractured section of a uniform bar becomes inevitably unequal in intensity. By changing the form of the fractured section in a particular way, the flow can be so altered that the stress over the whole fractured section becomes (very nearly) uniform in intensity. The material may be supposed to stand the same *maximum* intensity of stress in any case. But only the *average* intensity can be actually known from the experiment, and in the former case the average stress is much less than the maximum, while in the latter it is equal to the maximum. In the latter case, therefore, it is to be expected that higher loads should be carried, as experiment amply proves to be the case.

If this explanation of the matter be the correct one, a plate having simply a hole bored through it, and not symmetrically recessed at the sides, ought not to show nearly so much increase of strength. Fig. 7, Plate 31, shows the curves actually traced from such a piece. It did *not* show excess tensile resistance, and it *does* show *un*-uniform stress, so far confirming the explanation. In the riveted joints of Series VI. VII. and VIII., the want of the recesses at the sides was, on the whole, made up for by the number of holes and the narrowness of the side metal. But it will be noticed that, whether owing to the greater number of holes or not, Series VIII. gives a greater excess tensile resistance than any of the other joints.

In order to find how far the softness of the plates of Series V_A could be altered by annealing, six specimens cut from the $\frac{1}{4}$ in. plate and five from the $\frac{3}{8}$ in. plate, of the same size as those given in Table XV., were carefully annealed after machining. The result was to show a diminution of tenacity of $3 \cdot 3$ per cent. in the one case and $3 \cdot 6$ per cent. in the other. The ultimate extension was also diminished by just 2 per cent. in each case. Practically therefore annealing may be said to have made scarcely any difference in the plates.

Riveted Joints.—Tension, Shear, and Bearing Pressure.—The first experiments made on actual riveted joints were those of Series VI., of which the results are given in Tables XVI., XVII., and XVIII. Series VI. (*see* First Report, p. 366) consisted of twelve joints with two rivets each, proportioned in pairs to break by tearing and shearin respectively; and all in $\frac{3}{8}$ in. plate. Four specimens were made with $\frac{1}{2}$ in., four with $\frac{3}{4}$ in., and four with 1 in. rivets; and two out of each four with narrow, and two with wide pitch. The proportions of these joints were not intended to be those of practice, but such as should give to some extent limiting values for the resistances of the plate to tearing, and of the rivets to shearing and to pressure. The specimens were already riveted when received by the Author, so that he could only measure breadth, thickness, and lap directly. In making the calculations he had to assume that the rivets filled their holes, the diameters of which were given him by Mr. Boyd. The fractures appear to indicate that this was a quite justifiable assumption. The nominal and actual dimensions of the joints are given in Table XVI., which gives also the ratio of the shearing and of the bearing to the tearing areas. The tenacity of the plate was determined to be 29·97 tons per sq. in., by the experiments given in Table XVIII. on five strips cut from the same plates. (Three similar pieces annealed before testing gave a mean resistance of about 4·4 per cent. less, with about the same extension.)

The actual results of the tests are given in Table XVII. It will be seen that the $\frac{1}{2}$ in. joints all broke by tearing and the 1 in. joints by shearing; the $\frac{3}{4}$ in. joints breaking as they were intended to do. In the case of Nos. 377–380 ($\frac{1}{2}$ in. rivets) the joints always tore when the full tensile resistance of the metal was reached. The first pair had then only the very small shearing stress of 17 tons per sq. in., and the low bearing pressure of 19 tons per sq. in. Both shear and bearing pressure were higher in the second pair; but the latter was still very moderate, and the full shearing resistance was not reached. These are the only cases in which joints broken by tearing do not show the gain of strength in the plate which has been already examined. The author attributes this to the very small dimensions of the specimens. The whole solid breadth of the plate was only

0·69 in. in the one pair, and 0·94 in. in the other, and this in each case divided into three parts by two holes. Any error in the assumed size of the drilled holes, or any small inequality in the riveting, would of course have an excessive effect on such a very small amount of metal.

Nos. 381 and 382 ($\frac{3}{4}$ in. rivets) broke by tearing when the stress reached 34·40 tons per sq. in.; or 11·5 per cent. in excess of the strength of the untouched plate, exactly as was found in Series V. and V_A. The shearing stress was small (19·5 tons per sq. in.), and the bearing pressure still not excessive (31·6 tons). The rivet area was here 1·76 times, and the bearing area 1·09 times the net section of plate.

In the corresponding pair, Nos. 383 and 384, the joint gave way by shearing at a stress equal nearly to the mean shearing resistance of the material, 24·3 tons per sq. in. The tensile stress was moderate (25·83 tons per sq. in.), but the bearing pressure was very great, 39·64 tons per sq. in. It is remarkable that these joints, which sustained the maximum bearing pressure, also sustained the maximum shearing stress before they gave way.

In the last four specimens the rivets sheared at an exceptionally low stress. In Nos. 385 and 386 a tensile resistance equal to that of the untouched plate was reached without the plate tearing. The joint gave way finally by the shearing of the rivets at only 16·63 tons per sq. in., the bearing pressure being 35 tons per sq. in. In Nos. 387 and 388, proportioned to give way by shearing, the bearing pressure was 36·18 tons per sq. in., and the rivets sheared at 17·29 tons per sq. in., with a tensile stress barely up to the limit of elasticity.

In 387–8 it was clear that the joint must give way by shearing, for the full shearing resistance of the metal must have been reached long before the full tensile resistance; but this does not account for the very low shearing resistance. In 385–6 there is still more difficulty in accounting for it, for there the full tensile resistance obtained in 381–2 would have been reached with a shearing stress of only 19·4 tons per sq. in., and it might reasonably have been expected that the joints would break exactly as 381–2. Negatively one or two points are clear. A high tensile stress is not the cause of

the low shear, for in 387–8 the tension is not fairly past the limit of elasticity. The high bearing pressure also, although it may have determined the joint to give by shearing, can hardly be supposed to have so greatly reduced the shearing resistance; for a still higher pressure in 383–4 proved not incompatible with a much higher shearing resistance. From measurements made after fracture there is every appearance of the 1 in. rivets having filled their holes as well as the $\frac{3}{4}$ in. It is quite possible that the steel used for the larger rivets had a smaller shearing resistance than that used for the small ones, but it is unfortunately not possible to verify any such conjecture. Table XI. however shows that very great differences may exist in the shearing resistances of different bars. It seems probable that one general conclusion as to bearing pressure may be drawn from this series of experiments, and so far as it goes this conclusion is corroborated by all the later experiments. A bearing pressure of from 36 to 40 tons per sq. in. seems to be sufficient to compel a joint to give way by shearing, even in some cases at a very low shearing resistance. No case has occurred where the joint has torn, and where at the same time the pressure exceeded 35 tons per sq. in., although in some cases shearing has only occurred when the pressure reached nearly 40 tons per sq. in. Further experiments would however be necessary really to settle this point. In any case the conditions would of course be altered with other than single-riveted lap joints.

The last three columns of Table XVII. show the proportionate strength of the joints. The first four are weak, as might be expected. Nos. 381 and 382 give the best results, the joint having 55 per cent. of the strength of the solid plate; and Nos. 383 and 384 are nearly as good. It is very satisfactory to note that three seven-rivet joints in Series VIII. (Nos. 653, 1 to 3) proportioned very similarly to 381–2, gave almost identical results. Of the joints with 1 in. rivets, the first pair has a strength of 53·5 per cent., while the other has less than 42 per cent. of the strength of the solid plate.

It was attempted to observe the behaviour of these joints under test, by scribing a line across the planed edges of the two plates before pulling them, and observing the load at which the two halves

of this line separated, *i.e.* the point at which the joint began to slip. The results obtained in this fashion cannot be considered more than approximations, but may have some interest. In the first four joints ($\frac{1}{2}$ in. rivets), slip began to be visible when the tensile stress in the metal reached $8\frac{1}{2}$ tons per sq. in., and in the last four (1 in. rivets) at exactly the same stress. The joints with $\frac{3}{4}$ in. rivets stood a pull of $13\frac{1}{2}$ tons per sq. in. before any slip was visible. In all cases some perceptible bending of the joint, endeavouring to get itself into the line of pull, began very early. An attempt was also made to determine the load at which the edges of the joint had opened sufficiently, in bending, to allow a slip of paper to be pushed in. The results were not perhaps so irregular as might have been expected. So far as they go, they show that distinct opening occurs at very low stresses in many cases, and at lower stresses in the large than in the small joints. The four small joints, with $\frac{1}{2}$ in. rivets, each opened when the pull was about 13 tons per sq. in.; Nos. 381, 382, when the stress was 8·8 tons; Nos. 383, 384, at 5·5 tons; Nos. 385, 386 at 6·4 tons; and Nos. 387, 388 at only 3·3 tons per sq. in. The figures show very distinctly the way in which the tightness of a joint is affected by the pitch of the rivets.

Riveted Joints.—Margin and Pitch.—The results of the experiments in Series VII. will be found in Tables XIX. to XXI. This series consisted of six joints only, of different proportions. All had three $\frac{3}{4}$ in. rivets: the first three (431–433) had the same pitch but varying "margin" (or distance from edge of holes to edge of plate); and the last three (434–436) had the same margin but different pitches. The dimensions of the whole are given in Table XIX., to which the same remarks apply as were before made on Table XVI. The tenacity of the plates was determined by the tests of four strips cut from them, as given in Table XXI. It was almost precisely the same as in Series VI., viz., 29·9 tons per sq. in. Two strips of the same plate, annealed previous to testing, showed a tenacity of 2·7 per cent. less, with about the same extension.

All the joints broke by shearing the rivets. In the first three a mean tensile stress as high as 34·09 tons per sq. in. was reached without tearing, or 11·4 per cent. more than the breaking load of the

untouched plate, although the plate was not fractured. The bearing pressure was 35·83 tons per sq. in., and fracture occurred by shearing at 22 tons per sq. in., in spite of the high tensile stress. All three joints had the same shearing area, and all broke practically at the same total load, *i.e.* with the same intensity of shearing stress. The small differences of tensile stress and bearing pressure appear to be only what is due to the fact that the plates were not of uniform thickness, and that in consequence of this No. 431 had the smallest and No. 433 the largest tearing and bearing areas. It will be seen from the last column of the Table that with No. 431 a strength equal to 59·7 per cent. of that of the solid plate was obtained, an exceptionally good result for a single-riveted lap-joint. The small diminution apparent in this respect in Nos. 432 and 433 is due to the cause just explained. The plates were thicker, and are therefore credited with a greater strength; but, as the joints all gave way by shearing, the actual strength of the plate never came into account, and did not affect the breaking load. It does not appear that any effect can be traced to the change of margin from 1 in. down to $\frac{3}{4}$ in.

In the three other specimens of Series VII., Nos. 434 to 436, the margin was kept nominally $\frac{3}{4}$ in., or the same as in No. 433, and was actually but very slightly different, as is shown in Table XIX. The breadth of the plate and the pitch of the rivets were varied, all other dimensions remaining unchanged. All the joints however broke by shearing; and their strength remained therefore unaffected by the alteration in the area of the plate. It will be seen that the three specimens broke under a mean shearing stress of 21·37 tons per sq. in., and with a bearing pressure of 35·18 tons per sq. in. The apparent reduction of tensile stress from 31·78 to 25·42 tons per sq. in. is of course due simply to the increase of the tearing area, and not to any incapacity in the metal to stand the larger stress. It is noticeable that a variation in tensile stress between 25 and 35 tons per sq. in. does not appear to make the least difference in the ultimate shearing resistance of the section—a fact that could hardly have been considered to be *a priori* probable. It will be seen from the subsequent experiments that, even at a considerably lower bearing

pressure than that existing here, the rivets seldom stood more than 22 tons per sq. in. before shearing: which makes it appear probable that a result which at first might be easily attributed to excessive bearing pressure was partly, if not wholly, due to other causes, which will be mentioned later on.

The point at which slipping commenced was not observed in Series VII. The point at which opening out of the joint began was very irregular indeed, varying from 15·9 per cent. of the breaking load in No. 434, to 44·3 per cent. in No. 433. In mean it was 33·2 per cent.

Riveted Joints, Final Series.—The last set of specimens tested (Series VIII.) consisted of eighteen riveted joints, all of the single-riveted lap type, each with seven rivets. These joints, which required a total pull of from 70 to 80 tons for their fracture, were tested upon the machine belonging to the Barrow Hæmatite Steel Works (kindly placed at the disposal of the Institution for the purpose), by Mr. E. Richards and the author. The eighteen specimens were arranged in six sets of three each, each set being differently proportioned. These sets are numbered 652 to 657 in the Tables. No. 652 was intended to have such proportions (as far as could be judged from the earlier experiments) as to be equally likely to give way by tearing or by shearing. The intensity of the shearing stress was intended to be two-thirds of that of the tensile stress, while the bearing pressure per sq. in. was intended to be about 7½ per cent. greater than the tension. No. 653 was proportioned with excess of shearing or rivet area, No. 654 with defect of shearing area, No. 655 with excess of tearing or plate area, No. 656 with defect of tearing area, and No. 657 with excess of bearing pressure: the different proportions being arrived at by varying the pitch and diameter of the rivets, and in the case of No. 657 the thickness of the plate also. The "margin" in all cases was ¾ in. As to breadth, pitch, and margin, the specimens were all made to gauges prepared by the author to the particular sizes required. The preparation was done by Messrs. Geo. Wailes & Co.: after machining, each plate was carefully measured up with vernier callipers, and the actual dimensions were of course used in the calculations.

The riveting, which was by hand, was again done at the works of Mr. William Boyd, so as to ensure the same class of work as before. It is assumed in the calculations that the rivets filled the holes drilled for them, and there is every indication that this was the case.

The intended proportions of the joints were somewhat interfered with by the fact that the thickness of the plates was rather full throughout, the mean thickness of the plates nominally $\frac{3}{8}$ in. being $0 \cdot 396$ in., or $5 \cdot 6$ per cent. in excess, and that of the plate nominally $\frac{5}{16}$ in. being $0 \cdot 347$ in., or 11 per cent. in excess. It therefore happens that some of the joints, which were proportioned to give way by tearing, broke ultimately by the shearing of the rivets. In spite of this however, the experiments give practically all the information that was expected from them.

Table XXII. gives the measured dimensions of the joints (the means for each set of three), as well as the actual ratios of shearing and bearing areas to tearing area. Table XXIII. gives the general results of the experiments, which will be dealt with immediately. Table XXIV. gives the tenacity of ten strips cut from the $\frac{3}{8}$ in. and three from the $\frac{5}{16}$ in. plate, with other particulars as to the material. It will be seen that it is very closely similar to that of the plates used for the former experiments, having a tensile resistance of $29 \cdot 33$ tons per sq. in., and an ultimate extension of $23 \cdot 2$ per cent. in 10 in.; exactly the same figures as the means for Series I. and II., given in Table VII. Table XXV., lastly, gives the shearing and tensile resistance of the rivet steel used in Series VIII. The shearing resistance was measured in the apparatus formerly described. The steel tested in Nos. 728–1 to 728–6 was that used for the $\frac{3}{4}$ in. rivets in the joints Nos. 652, 655, 656, and 657, and gave a shearing resistance of $26 \cdot 33$ tons per sq. in., with something like a limit of elasticity at $70 \cdot 3$ per cent. of the breaking load. This resistance is about the same as that of the $\frac{15}{16}$ in. bar in Table XI., and therefore considerably more than that of the $1\frac{1}{16}$ in. and the $\frac{11}{16}$ in. bar. A piece of the same steel broken by tension gave a resistance of $29 \cdot 03$ tons per sq. in., so that the shearing resistance in this case was $90 \cdot 7$ per cent. of the tensile.

The results obtained by breaking the joints are given in

Table XXIII., which is arranged on the same general plan as Tables XVII. and XX. The three joints, No. 652, all broke by shearing at nearly the same total load (average 73·26 tons). The mean shearing stress was 21·46 tons per sq. in., or about 18·5 per cent. lower than the full resistance to shearing. The mean bearing pressure was only 33·17 tons per sq. in., and the tension 31·36 tons per sq. in., or 6·9 per cent. higher than the natural tenacity, although the plate did not tear. The proportions and results were very much the same as those of 434 (Series VII., Table XX.). No. 653 was proportioned with excess of rivet area (by the use of larger rivets), and a consequent slight increase of bearing area; the plate area was kept the same. These joints were expected to break by tearing the plate, but in the result only one went in this fashion, the rivets being sheared in the other two. This was partly due to the excess thickness of plate, which gave 6·4 per cent. additional tearing area, and partly to the fact that the rivets sheared (in the two joints which broke by shearing) at 18·23 tons per sq. in. only, or about 16·5 per cent. below the average of the other sheared joints. This cannot have been due to excessive bearing pressure (which only reached 31·5 tons per sq. in.), nor could any signs of defective riveting, or of the rivets not having filled up the holes, be detected. On examining Table XI. however, it will be seen that there was there as much as 14 per cent. difference between the shearing resistance of two sizes of rivet steel; and it is probable that the larger rivet steel used for No. 653 (and not for any of the others) had in the same way a smaller resistance. Unfortunately there was no opportunity of testing the shearing resistance of this larger diameter. It will be remembered that it was the largest size of rivet in Series VI. (Table XVII.) which also gave so low a shearing resistance. The proportions of No. 653 however are obviously very nearly those of uniform strength for this weaker rivet steel (or for rivets which for any reason can shear at so low a stress); for one of the three joints of the set broke by tearing. The tensile stress at fracture of this joint was 33·48 tons per sq. in., or 14·1 per cent. more than the tenacity of the plate, and the strength of the joint as a whole was 56·2 per cent. of

the strength of the solid plate. The mean strength of the three joints, as compared with that of the solid plate, was 54·8 per cent. It will be noticed that a stronger rivet steel could not here have greatly increased the resistance of the joints, as the tensile stress on them was already very nearly up to the breaking load.

No. 654 was made with defect of rivet area, by using small rivets and keeping the plate section the same; and No. 655 with excess of plate area, by increasing the pitch with the use of the standard sized rivets ($\frac{3}{4}$ in.). Both sets broke, as was expected, by shearing. The smaller rivets stood a somewhat greater shearing stress than the others; but practically the joints were of the same strength, viz., 55 per cent. of that of the solid plate: so that all four proportions, 652 to 655, were very closely of the same strength.

The three joints of No. 656 were made with reduction of plate area, by reducing the pitch, keeping the $\frac{3}{4}$ in. rivets as before. Two of them tore through the plate, as was expected, the third broke by shearing the rivets. The cause of the latter mode of fracture however may have been a defective rivet, for, although all the rivets gave way simultaneously, one gave by the tearing off of both ends, instead of by shearing, and appeared to have been somewhat burnt; and another showed a partly crystalline fracture. The mean tensile stress when the joints broke was 36·13 tons per sq. in. or 23·2 per cent. more than the tenacity of the plate. Taking only the two joints which broke by tearing the plate, the stress reached 36·7 tons per sq. in., or 25·1 per cent. more than the tenacity of the plate. By this extremely high figure the strength of these joints is brought up to 58·6 per cent. of that of the solid plate. If the author's explanation of the cause of the increase of strength due to perforation be a correct one, anything which tended (within certain limits) to exaggerate the effect of flow already described should strengthen the metal. It seems probable that the narrowing of the metal between the holes in this case has had just such an effect, and may be looked on as a probable cause of the increased resistance to tension.

The last set of joints tested were numbered 657, and were of thinner plate, with the object of getting the same tearing and shearing area as in No. 652, with decrease of bearing area. The thickness of

the plates however was 0·347 in. instead of $\frac{5}{16}$ in., so that the very high pressure wished for was not obtained. The highest pressure in any one case was 42·56 tons per sq. in., the mean of the three being 39·71 tons per sq. in. This pressure, somewhat higher than appeared from the former experiments to be allowable, still does not seem to have sensibly affected the shearing resistance, which reached an average of 22·09 tons per sq. in. before the rivets sheared. The mean strength of the three joints was 60·8 per cent. of that of the solid plate, and the highest single result (given in the Table) was 63·7 per cent. The tensile stress when the rivets sheared was (in mean) 32·56 tons per sq. in., or 11 per cent. more than the tenacity of the untouched plate.

The point at which visible slipping of the plates of each joint on one another commenced was observed (with the aid of a magnifying glass) as closely as was practicable; and the results are given in Table XXIII. In the mean, slip occurred at about 23·5 per cent. of the breaking load, but in some cases it was visible very much sooner even than this. The points observed do not appear to bear any particular ratio either to the strength of the joint or the pitch of the rivets.

In summing up the results of Series VIII. it should be said first of all that the fractures were throughout very satisfactory. In only one case (652–3), did one rivet give slightly before the others, and this particular case happened to be the one of its set which stood the greatest shearing stress. Out of all the rivets sheared, four only showed traces of crystalline structure; and two gave way at the heads instead of by shearing. The riveting seems to have been very sound throughout. In the three joints which tore through the plate, the mean tensile stress at fracture was 35·62 tons per sq. in., or 21·4 per cent. more than the tenacity of the solid plate. In the fifteen joints which gave way by shearing (including those of No. 653) the mean shearing stress at fracture was 21·5 tons per sq. in., or 18·3 per cent. less than the full shearing resistance of the rivet steel. The increase of tensile resistance has already been discussed. The decrease of shearing resistance may no doubt be largely due to the fact that the rivets are in tension as well as in shear, tension due to

the opening out of the plates before the joint breaks. The Author has in hand some experiments, which he hopes to be able to lay before the Institution, with a view to finding out what shearing resistance the rivet itself has, when tested under conditions exactly similar to those under which the other shearing experiments (Tables XI. and XXV.) were made.

General Results.—The graduated experiments of Series VIII. allow very clear deductions to be made as to the best proportions for certain important types of riveted joint. The strongest proportions are those of Nos. 656 and 657. The difference between them is not very great at first sight, but is in reality more than may appear. The joints of No. 656 owe their great resistance entirely to the excess tensile stress which they sustained; and without further experience it is not possible to count on always obtaining such a great excess, far higher than is indicated by the other experiments. Moreover the close pitch makes the joint an expensive one, and the deficiency in plate area is in almost all cases a deficiency in the wrong direction. It is therefore clear that No. 657 is by far the best type of joint among those tested, and it can hardly be expected under any circumstances to obtain a single-riveted lap joint which has an average of more than 61 per cent. of the strength of the solid plate. In No. 657 the ratio of rivet to plate area (see Table XXII.) was $1 \cdot 47 : 1$, and of bearing to plate area, $0 \cdot 82 : 1$. Calling then the pitch of a single-riveted lap joint p, the diameter of the rivet holes d, and the thickness of plate t, we obtain for the equations connecting these three quantities,

$$1 \cdot 47 \, (p - d) \, t = \frac{\pi}{4} d^2,$$

and

$$0 \cdot 82 \, (p - d) \, t = td.$$

Worked out, this gives

$$p = 2 \cdot 22 \, d,$$
$$d = 2 \cdot 28 \, t;$$

which may be at once rounded off to

pitch = $2 \cdot 25$ diameter of hole,
diameter of hole = $2 \cdot 25$ thickness of plate,

which would thus represent the proportions (supposing they could conveniently be used) of a single-riveted lap joint, with steel plates and rivets, of maximum strength.

The joints in No. 657 already had a small excess of plate area; and this "rounding off" of the figures would give a little more. For boilers it would probably be advisable to increase the ratio of pitch to diameter of hole to $2 \cdot 3$ or $2 \cdot 4$. The diameter of the rivet will be about $\frac{1}{32}$ inch less than the diameter of the hole.

Although only one type of joint (single-riveted lap with drilled holes) was tested, the experiments enable some inferences to be drawn respecting others. With the wider pitch of double-riveted joints, the excess tenacity of the plate will be much less, and with chain-riveted joints of ordinary proportions it will altogether disappear. For the latter it will not be safe to assume a greater tensile stress than the ordinary resistance of the material. For butt joints, on the other hand, if they have double cover-plates, the shearing resistance of the rivets will approach much more nearly the shearing resistance of the steel out of which they have been made; and even in a double-riveted lap joint the shearing resistance per sq. in. should be somewhat greater than in a single-riveted one, on account of the greater stiffness given to the plates by the broad lap.

If we take a double-riveted lap joint (of the materials used in the experiments) to be equally likely to break either way when the tensile stress is $31 \cdot 5$ tons per sq. in., the shearing stress $23 \cdot 0$ tons per sq. in., and the bearing pressure 40 tons per sq. in., we should get for proportions of uniform (and maximum) strength

$$\text{pitch} = 3 \cdot 54 \text{ diameter of hole,}$$

$$\text{diameter} = 2 \cdot 21 \text{ thickness of plate;}$$

and if the plate had a natural tenacity of $29 \cdot 5$ tons per sq. in., such a joint would have a strength equal to nearly 77 per cent. of that of the solid plate.

The effect of substituting punched for drilled holes can be estimated from the results given in Tables XII. and XIV. The excess of tensile resistance over that of the untouched plate is reduced to about 6 per cent.

The joints experimented on were all made in $\frac{5}{8}$ in. plate. The results probably hold good for $\frac{1}{2}$ in. plate also; but for $\frac{3}{4}$ or 1 in. plate the excess of tensile resistance will probably be considerably reduced in practice by the comparatively much larger pitch which then becomes necessary. Even for $\frac{1}{2}$ in. plate the large proportion of rivet diameter to thickness ($d = 2 \cdot 25\, t$) would be at best very inconvenient, and for greater thicknesses it would be impracticable. The proportional strength of the best practicable single-riveted joint will therefore decrease very much as the thickness increases.

It is worth while, from a practical point of view, to notice that the results of the experiments of Series VIII., joints with seven rivets, do not differ from the earlier results of joints with three rivets, or even with two, in any way that can be attributed to the greater breadth; and therefore there seems no valid reason for refusing to accept, as applicable within proper limits to large joints, results obtained from experiments made on much smaller ones. The only exception to be made to this is that perhaps the larger value of the excess tensile resistance in Series VIII., compared with the former experiments, may be partly due to the great width of the joints having counteracted any weakening effect (as compared with Series V. and V_A.) of the straight sides in the smaller joints.

The Author would like once again to point out that, for the reasons already given, he has confined himself entirely to a statement and discussion of his own results, without comparing them with those of others. He may however be permitted to express his gratification that the recent admirable memoir published by the Board of Trade on this subject contains results which agree in every important respect with those just described, so far as they cover the same ground.

RIVETED JOINTS.—TABLE I.

SERIES I.—GENERAL RESULTS.—(*Tenacity of Steel Boiler Plates.—Specimens pulled from Pins.*)

Test No.	Dimensions.			Limit of Elasticity.		Breaking Load. (On original Area.)		Ratio of Limit to Breaking Load.	Ultimate Extension in 10 in.	Remarks, &c.
	Breadth. In.	Thickness. In.	Area. Sq. In.	Pounds per sq. in.	Tons per sq. in.	Pounds per sq. in.	Tons per sq. in.	Per cent.	Per cent.	
268–1	1·388	0·252	0·350	47430	21·17	65810	29·38	72·1	21·5	
268–2	1·375	0·253	0·348	48840	21·81	68400	30 53	71·4	17·1	
268–3	1·384	0·252	0·349	46760	20·88	65100	29·06	71·8	20·2	
			Mean	**47680**	**21·29**	**66440**	**29·66**	**71 8**	**19·6**	
269–1	4·007	0·266	1·067	52930	23·63	67850	30·29	78·0	21·6	
269–2	4·000	0·265	1·060	51540	23·01	66870	29·85	77·1	19·2	
269–3	4·000	0·257	1·028	55720	24·88	71980	32·14	77·4	19·0	
			Mean	**53400**	**23·84**	**68900**	**30·76**	**77·5**	**19·9**	
		Mean of $\frac{1}{4}$ in. plate		**50540**	**22·56**	**67670**	**30·21**	**74·7**	**19·7**	
270–1	2·063	0·370	0·763	41730	18·63	62928	28·09	66·3	26·5	
270–2	2·060	0·370	0·762	39370	17·58	62450	27·89	63·0	26·8	
270–3	2·061	0·375	0·773	37910	16·92	61710	27·50	61·5	25·6	
			Mean	**39670**	**17·71**	**62360**	**27·83**	**63·6**	**26·3**	
271–1	3·493	0·367	1·282	40930	18·27	63530	28·36	64·4	27·4	
271–2	3·490	0·370	1·292	39090	17·45	63880	28·52	61·2	27·5	
271–3	3·488	0·374	1·304	36810	16·43	61350	27·39	60·0	28·1	
			Mean	**38940**	**17·38**	**62920**	**28·09**	**61·9**	**27·7**	
		Mean of $\frac{3}{8}$ in. plate		**39300**	**17·54**	**62640**	**27·96**	**62·7**	**27·0**	
272–1	2·755	0·500	1·372	38040	16·98	64280	28·70	59·2	23·4	
272–2	2·738	0·496	1·359	40840	18·23	65830	29·40	62·0	23·9	
272–3	2·755	0·497	1·369	37620	16·80	64280	28 70	58·5	26·8	
272–4	2·752	0·500	1·376	37070	16·55	65040	29·04	57·0	25·0	
		Mean of $\frac{1}{2}$ in. plate		**38390**	**17·14**	**64860**	**28 96**	**59·4**	**24·8**	

RIVETED JOINTS.—TABLE II.

SERIES I.—ULTIMATE EXTENSION OF SPECIMENS.—(*Steel Boiler Plate.—Specimens pulled from Pins.*)

Test No.	Nominal Dimensions.		Final permanent Extensions.						Tenacity.	Nature of Fracture, &c.
	Breadth. In.	Thickness. In.	In the $2\frac{1}{2}$ in. at fracture.		In $7\frac{1}{2}$ in. not including fracture.		In the 10 in. total length.		Tons per sq. in.	
			Actual in.	Per cent.	Actual in.	Per cent.	Actual in.	Per cent.		
268–1	$1\frac{3}{8}$	$\frac{1}{4}$	0·77	30·8	1·38	18·4	2·15	21·5	29·38	
268–2	,,	,,	0·75	30·0	0·96	12·8	1·71	17·1	30·53	Considerable local extension at two places.
268–3	,,	,,	0·92	36·8	1·10	14·7	2·02	20·2	29·06	
		Mean	**0·81**	**32·5**	**1·15**	**15·3**	**1·96**	**19·6**	**29·66**	
269–1	4	$\frac{1}{4}$	1·02	40·8	1·14	15·2	2·16	21·6	30·29	Irregularly across.
269–2	,,	,,	0·92	36·8	1·00	13·3	1·92	19·2	29·85	Obliquely across.
269–3	,,	,,	0·63	25·2	1·27	16·9	1·90	19·0	32·14	
		Mean	**0·86**	**34·3**	**1·14**	**15·1**	**1·99**	**19·9**	**30·76**	
	Mean, $\frac{1}{4}$ in. Plate		**0·83**	**33·4**	**1·14**	**15·2**	**1·97**	**19·7**	**30·21**	
270–1	2	$\frac{3}{8}$	1·11	44·4	1·54	20·5	2·65	26·5	28·09	
270–2	,,	,,	1·15	46·0	1·53	20·4	2·68	26·8	27·89	
270–3	,,	,,	1·10	44·0	1·46	19·5	2·56	25·6	27·50	
		Mean	**1·12**	**44·8**	**1·51**	**20·1**	**2·63**	**26·3**	**27·83**	
271–1	$3\frac{1}{2}$	$\frac{3}{8}$	1·33	53·2	1·41	18·8	2·74	27·4	28·36	Distressed on surface.
271–2	,,	,,	1·25	50·0	1·50	20·0	2·75	27·5	28·52	Irregularly across.
271–3	,,	,,	1·30	52·0	1·51	20·1	2·81	28·1	27·39	Axis very much distorted.
		Mean	**1·29**	**51·7**	**1·47**	**19·6**	**2·63**	**26·3**	**28·09**	
	Mean, $\frac{3}{8}$ in. Plate		**1·20**	**48·2**	**1·49**	**19·8**	**2·70**	**27·0**	**27·96**	
272–1	$2\frac{3}{4}$	$\frac{1}{2}$	1·12	44·8	1·22	16·3	2·34	23·4	28·70	
272–2	,,	,,	1·15	46·0	1·24	16·5	2·39	23·9	29·40	
272–3	,,	,,	1·26	50·4	1·42	18·9	2·68	26·8	28·70	
272–4	,,	,,	1·05	42·0	1·45	19·3	2·50	25·0	29·04	Surface a good deal distressed.
	Mean, $\frac{1}{2}$ in. Plate		**1·14**	**45·8**	**1·33**	**17·7**	**2·48**	**24·8**	**28·96**	

RIVETED JOINTS.—TABLE III.

SERIES I.—ELASTICITY OF SPECIMENS.—(*Steel Boiler Plate.—Specimens pulled from Pins.*)

Test No.	Nominal Dimensions. Breadth. In.	Nominal Dimensions. Thickness. In.	I. Permanent Set began. Tons per sq. in.	II. Uniform Extension ended. Tons per sq. in.	III. Steelyard dropped. Tons per sq. in.	IV. Broke. Tons per sq. in.	Ratio $\frac{I}{III}$	Ratio $\frac{II}{III}$	Ratio $\frac{I}{IV}$	$\Delta\epsilon$ Specific Extension. Thousandths of an Inch.	E Modulus of Elasticity. Pounds per sq. in.	Remarks.
268–1	$1\frac{3}{8}$	$\frac{1}{4}$	10·84	13·39	21·17	29·38				0·297	33,670,000	
268–2	,,	,,	11·11	14·11	21·81	30·53				0·364	27,450,000	
268–3	,,	,,	15·35	15·35	20·88	29·06				0·306	32,700,000	
		Mean	**13·43**	**14·28**	**21·29**	**29·66**	**0·631**	**0·671**	**0·453**	**0·322**	**31,060,000**	
269–1	4	$\frac{1}{4}$	9·41	21·97	23·63	30·29				—	—	
269–2	,,	,,	10·95	13·05	23·01	29·85				0·327	30,580,000	
269–3	,,	,,	19·54	21·77	24·88	32·14				—	—	
		Mean	**13·30**	**13·91**	**23·84**	**30·76**	**0·558**	**0·793**	**0·432**	**0·327**	**30,580,000**	
	Mean, $\frac{1}{4}$ in. Plate		**13·36**	**16·60**	**22·56**	**30·21**	**0·593**	**0·736**	**0·442**	**0·324**	**30,860,000**	
270–1	2	$\frac{3}{8}$	11·70	14·63	18·63	28·09				0·350	28,570,000	
270–2	,,	,,	10·55	11·42	17·58	27·89				0·333	30,000,000	
270–3	,,	,,	—	—	[16·92]	[27·50]				—	—	
		Mean	**11·12**	**13·02**	**18·10**	**27·99**	**0·614**	**0·719**	**0·397**	**0·341**	**29,320,000**	
271–1	$3\frac{1}{2}$	$\frac{3}{8}$	14·80	16·02	18·27	28·36				0·320	31,250,000	
271–2	,,	,,	13·82	16·58	17·45	28·52				0·330	30,200,000	
271–3	,,	,,	10·27	13·70	16·43	27·39				0·298	33,600,000	
		Mean	**12·96**	**15·43**	**17·38**	**28·09**	**0·746**	**0·888**	**0·461**	**0·316**	**31,640,000**	
	Mean, $\frac{3}{8}$ in. Plate		**12·23**	**14·47**	**17·67**	**28·05**	**0·692**	**0·819**	**0·436**	**0·326**	**30,680,000**	
272–1	$2\frac{3}{4}$	$\frac{1}{2}$	—	—	[16·98]	[28·70]				—	—	
272–2	,,	,,	8·21	14·78	18·23	29·40				0·353	28,350,000	
272–3	,,	,,	10·60	13·37	16·80	28·70				0·393	25,440,000	
272–4	,,	,,	8·92	10·39	16·55	29·04				0·355	28,140,000	
	Mean, $\frac{1}{2}$ in. Plate		**9·24**	**12·85**	**17·19**	**29·05**	**0·537**	**0·748**	**0·318**	**0·367**	**27,250,000**	

RIVETED JOINTS.—TABLE IV.

Series II.—General Results.—(*Tenacity of Steel Boiler Plates.—Specimens pulled in Wedge Grips.*)

Test No.	Dimensions.			Limit of Elasticity.		Breaking Load (On original Area).		Ratio of Limit to Breaking Load.	Percentage of ult. extension in 10 in.	Remarks, &c.
	Breadth.	Thickness.	Area.	Pounds	Tons	Pounds	Tons			
	In.	In.	Sq. In.	per sq. in.	per sq. in.	per sq. in.	per sq. in.	Per cent.	Per cent.	
273–1	1·361	0·248	0·337	54600	24·37	69420	30·95	0·787	18·8	
273–2	1·368	0·250	0 342	53810	24·02	69810	31·17	0·771	18·8	
273–3	1·370	0·255	0·349	52950	23·64	69450	31·00	0 763	19·4	
			Mean	**53790**	**24·01**	**69560**	**31·04**	**0·773**	**19·0**	
274–1	3·995	0·249	0·995	43720	19·52	64850	28·95	0·674	25·6	
274–2	3·998	0·250	0·999	43200	19·28	66720	29·79	0·647	25·2	
274–3	3·996	0·254	1·015	45240	20·19	65930	29·43	0·686	28·2	
			Mean	**44050**	**19·66**	**65830**	**29·39**	**0·669**	**26·3**	
		Mean of $\frac{1}{4}$ in. plate		**48920**	**21·83**	**67690**	**30·21**	**0·721**	**22·6**	
275–1	2·04	0·400	0·816	40190	17·94	66150	29·53	0·608	24·0	
275–2	2·056	0·400	0·822	41850	18·68	65760	29·36	0·636	25·0	
275–3	2·058	0·402	0·827	38450	17·17	65160	29·09	0·590	22·7	
			Mean	**40160**	**17 93**	**65690**	**29·33**	**0·611**	**23·9**	
276–1	3·500	0·380	1·330	41950	18·73	68800	30·71	0·610	23·2	
276–2	3·500	0·400	1·400	40570	18·11	65460	29·22	0·620	20·0	
276–3	3·488	0·380	1·325	42560	19·00	61330	27·38	0·694	21·4	
			Mean	**41690**	**18·61**	**65200**	**29·10**	**0·640**	**21·5**	
		Mean of $\frac{3}{8}$ in. plate		**40920**	**18·27**	**65440**	**29·21**	**0·626**	**22·7**	

RIVETED JOINTS.—TABLE V.

Series II.—Ultimate Extension of Specimens.—(*Steel Boiler Plate.—Specimens pulled in Wedge Grips.*)

Test No.	Nominal Dimensions.		Ultimate Permanent Extension.						Tenacity.	Nature of Fracture, &c.
	Breadth.	Thickness.	In the $2\frac{1}{2}$ in. at fracture.		In the $7\frac{1}{2}$ in. excluding fracture.		In the 10 in. total length.		Tons per sq. in.	
	In.	In.	Actual in.	Per cent.	Actual in.	Per cent.	Actual in.	Per cent.		
273–1	$1\frac{3}{8}$	$\frac{1}{4}$	0·77	30·8	1·11	14·8	1·88	18·8	30·95	
273–2	,,	,,	0·73	29·2	1·15	15·3	1·88	18·8	31·17	
273–3	,,	,,	0·78	31·2	1·16	15·5	1·94	19·4	31·00	
		Mean	**0·76**	**30·4**	**1·14**	**15·2**	**1·90**	**19·0**	**31·04**	
274–1	4	$\frac{1}{4}$	1·15	46·0	1·41	18·8	2·56	25·6	28·95	Obliquely across specimen.
274–2	,,	,,	1·17	46·8	1·35	18·0	2·52	25·2	29·79	Do.
274–3	,,	,,	1·24	49·6	1·58	21·1	2·82	28·2	29·43	Do.
		Mean	**1·19**	**47·5**	**1·45**	**19·3**	**2·63**	**26·3**	**29·39**	
	Mean, $\frac{1}{4}$ in. Plate		**0·97**	**38·9**	**1·29**	**17·2**	**2·26**	**22·6**	**30·21**	
275–1	2	$\frac{3}{8}$	1·00	40·0	1·40	18·7	2·40	24·0	29·53	
275–2	,,	,,	0·94	37·6	1·56	20·8	2·50	25·0	29·36	Some trades of longitudinal splitting.
275–3	,,	,,	1·00	40·0	1·27	16·9	2·27	22·7	29·09	Do. Do. Do.
		Mean	**0·98**	**39·2**	**1·41**	**18·8**	**2·39**	**23·9**	**29·33**	
276–1	$3\frac{1}{2}$	$\frac{3}{8}$	1·10	44·0	1·22	16·3	2·32	23·2	30·71	
276–2	,,	,,	0·72	28·8	1·25	16·7	1·97	19·7	29·22	Centre line very much distorted.
276–3	,,	,,	1·08	43·2	1·06	14·1	2·14	21·4	27·38	Do. Do. Do.
		Mean	**0·97**	**38·7**	**1·18**	**15·7**	**2·14**	**21·4**	**29·10**	
	Mean, $\frac{3}{8}$ in. Plate		**0·975**	**39·0**	**1·29**	**17·2**	**2·26**	**22·6**	**29·21**	

RIVETED JOINTS.—TABLE VI.

Series II.—Elasticity of Specimens.—(*Steel Boiler Plates.—Specimens pulled in Wedge Grips.*)

Test No.	Nominal Dimensions. Breadth. In.	Nominal Dimensions. Thickness. In.	I. Permanent Set began. Tons per sq. in.	II. Uniform Extension ended. Tons per sq. in.	III. Steelyard Dropped. Tons per sq. in.	IV. Broke. Tons per sq. in.	Ratio. $\frac{I}{III}$	Ratio. $\frac{II}{III}$	Ratio $\frac{I}{IV}$	$\Delta\epsilon$ Specific Extension. Thousandths of an inch.	E Modulus of Elasticity. Pounds per sq. in.
273–1	$1\frac{3}{8}$	$\frac{1}{4}$	11·26	13·25	24·37	30·95				0·383	26,110,000
273–2	,,	,,	11·10	11·75	24·02	31·17				0·360	27,770,000
273–3	,,	,,	12·15	14·71	23·64	31·00				0·351	28,250,000
		Mean	**11·50**	**13·23**	**24·01**	**31·04**	**0·479**	**0·551**	**0·370**	**0·365**	**27,400,000**
274–1	4	$\frac{1}{4}$	8·53	12·31	19·52	28·95				—	—
274–2	,,	,,	8·93	10·05	19·28	29·79				0·316	31,640,000
274–3	,,	,,	9·90	13·20	20·19	29·43				—	—
		Mean	**9·12**	**11·86**	**19·66**	**29·39**	**0·464**	**0·603**	**0·310**	**0·316**	**31,640,000**
	Mean, $\frac{1}{4}$ in. plate		**10·31**	**12·54**	**21·83**	**30·21**	**0·472**	**0·574**	**0·341**	**0·353**	**28,330,000**
275–1	2	$\frac{3}{8}$	10·39	10·94	17·94	29·53				0·369	27,100,000
275–2	,,	,,	11·13	11·13	18·68	29·36				0·353	28,330,000
275–3	,,	,,	8·10	8·10	17·17	29·09				0·313	31,940,000
		Mean	**9·87**	**10·06**	**17·93**	**29·33**	**0·550**	**0·561**	**0·336**	**0·345**	**28,980,000**
276–1	$3\frac{1}{2}$	$\frac{3}{8}$	—	—	[18·73]	[30·71]				—	—
276–2	,,	,,	—	—	[18·11]	[29·22]				—	—
276–3	,,	,,	9·44	15·16	19·00	27·38				0·319	31,350,000
		Mean	**9·44**	**15·16**	**19·00**	**27·38**	**0·497**	**0·798**	**0·345**	**0·319**	**31,350,000**
	Mean, $\frac{3}{8}$ in. plate		**9·76**	**11·33**	**18·20**	**28·84**	**0·536**	**0·623**	**0·338**	**0·338**	**29,590,000**

RIVETED JOINTS.—TABLE VII.

SUMMARY AND COMPARISON OF RESULTS, SERIES I. AND II.—(*Tenacity of Steel Boiler Plates.*)

Test Number.	Nominal Dimensions. Breadth.	Nominal Dimensions. Thickness.	Limit Drop of Steelyard.	Breaking Load.	Ratio of Limit to Breaking Load.	Percentage of Ultimate Extension in 10 in.	Tenacity compared with that of similar specimens held by Wedges.	Tenacity compared with that of similar specimens held by Pins.	$\Delta\epsilon$ Specific Extension.	E Modulus of Elasticity.	Remarks, &c.
	In.	In.	Tons per sq. in.	Tons per sq. in.					Thousandths of an inch.	Pounds per sq. in.	
268–1 to 268–3	$1\frac{3}{8}$	$\frac{1}{4}$	21·29	29·66	0·718	19·6	0·956	1·000	0·322	31,060,000	
273–1 to 273–3	,,	,,	24·01	31·04	0·773	19·0	1·000	1·046	0·365	27,400,000	
		Mean	**22·65**	**30·35**	**0·745**	**19·3**			**0·343**	**29,160,000**	
269–1 to 269–3	4	$\frac{1}{4}$	23·84	30·76	0·775	19·9	1·047	1·000	0·327	30,580,000	269–2 only, for $\Delta\epsilon$ and E.
274–1 to 274–3	,,	,,	19·66	29·39	0·669	26·3	1·000	0·955	0·316	31,640,000	274–2 only, for $\Delta\epsilon$ and E.
		Mean	**21·75**	**30·07**	**0·722**	**23·1**			**0·321**	**31,150,000**	
	Mean, $\frac{1}{4}$ in. Plate		**22·20**	**30·21**	**0·733**	**21·2**			**0·338**	**29,590,000**	
270–1 to 270–3	2	$\frac{3}{8}$	17·71	27·83	0·636	26·3	0·949	1·000	0·341	29,320,000	270–1 and 270–2 only, for $\Delta\epsilon$ and E.
275–1 to 275–3	,,	,,	17·93	29·33	0·611	23·9	1·000	1·050	0·345	28,980,000	
		Mean	**17·82**	**28·58**	**0·623**	**25·1**			**0·343**	**29,160,000**	
271–1 to 271–3	$3\frac{1}{2}$	$\frac{3}{8}$	17·38	28·09	0·619	27·7	0·965	1·000	0·316	31,640,000	
276–1 to 276–3	,,	,,	18·61	29·10	0·640	21·5	1·000	1·036	0·319	31,350,000	276–3 only, for $\Delta\epsilon$ and E.
		Mean	**17·99**	**28·59**	**0·629**	**24·6**			**0·317**	**31,550,000**	
	Mean, $\frac{3}{8}$ in. Plate		**17·90**	**28·59**	**0·626**	**24·8**			**0·332**	**30,120,000**	
272–1 to 272–4	$2\frac{3}{4}$	$\frac{1}{2}$	17·14	28·96	0·594	24·8			0·367	27,250,000	Not tested with wedges. 272–2 to 272–4 only, for $\Delta\epsilon$ and E.
	Mean of all Plates, $\frac{1}{4}$, $\frac{3}{8}$, & $\frac{1}{2}$ inch 28 in all		**19·63**	**29·34**	**0·669**	**23·3**			**0·339**	**29,500,000**	Mean values of $\Delta\epsilon$ and E from twenty plates.

RIVETED JOINTS.—TABLE VIII.

Series III.—General Results.—(*Tenacity of Rivet Steel.*)

Test No.	Dimensions.			Limit of Elasticity.		Breaking Load (On original area).		Ratio of Limit to Breaking Load.	Ultimate Extension in 10 in.
	Original Diameter of Bar.	Diameter as Tested.	Area.	Pounds	Tons	Pounds	Tons.		
	In.	In.	Sq. In.	per sq. in.	per sq. in.	per sq. in.	per sq. in.	per cent.	per cent.
277–1	$\frac{11}{16}$	0·512	0·206	43400	19·38	64770	28·92	0·670	22·5
277–2	,,	0·505	0·200	45200	20·18	65500	29·24	0·690	23·5
277–3	,,	0·507	0·201	45780	20·44	65770	29·36	0·696	16·8
			Mean	**44790**	**20·00**	**65350**	**29·17**	**0·686**	**20·9**
278–1	$\frac{15}{16}$	0·616	0·298	46370	20·70	67960	30·34	0·682	19·2
278–2	,,	0·622	0·303	46200	20·63	69310	30·94	0·667	21·3
278–3	,,	0·616	0·298	46220	20·63	69210	30·90	0·668	19·1
			Mean	**46260**	**20·65**	**68830**	**30·73**	**0·672**	**19·9**
279–1	$1\frac{1}{16}$	0·804	0·507	48600	21·70	60280	26·91	0·806	21·6
279–2	,,	0·804	0·507	47730	21·31	60750	27·12	0·786	22·2
279–3	,,	0·786	0·485	46750	20·87	63500	28·35	0·736	26·0
			Mean	**47690**	**21·29**	**61510**	**27·46**	**0·775**	**23·3**
	Mean of 9 specimens			**46250**	**20·65**	**65230**	**29·12**	**0·710**	**21·4**

RIVETED JOINTS.—TABLE IX.

SERIES III.—ULTIMATE EXTENSION OF SPECIMENS.—(*Rivet Steel.*)

Test No.	Original Diameter of Bar. In.	Ultimate Extension. In the $2\frac{1}{2}$ in. at fracture. Actual in.	Per cent.	In the $7\frac{1}{2}$ in. excluding fracture. Actual in.	Per cent.	In the 10. in. total length. Actual in.	Per cent.	Tenacity. Tons per sq. in.	Position of Fracture, &c.
277–1	$\frac{11}{16}$	0·88	35·2	1·37	18·3	2·25	22·5	28·92	About 1 in. from one end.
277–2	,,	0·87	34·8	1·48	19·7	2·35	23·5	29·24	In middle.
277–3	,,	0·64	25·6	1·04	13·9	1·68	16·8	29·36	About $1\frac{1}{2}$ in. from one end.
	Mean	**0·80**	**31·9**	**1·30**	**17·3**	**2·09**	**20·9**	**29·17**	
278–1	$\frac{15}{16}$	0·73	29·2	1·19	15·9	1·92	19·2	30·34	About 1 in. from one end.
278–2	,,	0·77	30·8	1·36	18·1	2·13	21·3	30·94	,, ,, ,,
278–3	,,	0·78	31·2	1·13	15·1	1·91	19·1	30·90	,, ,, ,,
	Mean	**0·76**	**30·4**	**1·23**	**16·4**	**1·99**	**19·9**	**30·73**	
279–1	$1\frac{1}{16}$	0·86	34·4	1·30	17·3	2·16	21·6	26·91	About 1 in. from one end.
279–2	,,	0·86	34·4	1·36	18 1	2·22	22·2	27·12	,, ,, ,,
279-3	,,	0·96	38·4	1·64	21·9	2·60	26·0	28·35	In middle.
	Mean	**0·89**	**35·7**	**1·43**	**19·1**	**2·33**	**23·3**	**27·46**	
	Mean of all sizes	**0·82**	**32·7**	**1·32**	**17·6**	**2·14**	**21·4**	**29·12**	

RIVETED JOINTS.—TABLE X.

SERIES III.—ELASTICITY OF SPECIMENS.—(*Rivet Steel.*)

Test No.	Original Diameter of Bar. In.	I. Permanent Set began. Tons per sq. in.	II. Uniform Extension ends. Tons per sq. in.	III. Steelyard Dropped. Tons per sq. in.	IV. Broke. Tons per sq. in.	Ratio $\frac{I}{III}$	Ratio $\frac{II}{III}$	Ratio $\frac{I}{IV}$	$\Delta\epsilon$ Specific Extension. Thousandths of an inch.	E Modulus of Elasticity. Pounds per sq. in.	Remarks.
277–1	$\frac{11}{16}$	15·82	16·47	19·38	28·92	0·816	0·850	0·547	0·324	30,860,000	
277–2	,,	16·29	16·29	20·18	29·24	0·807	0·807	0·557	0·328	30,490,000	
277–3	,,	—	—	[20·44]	[29·36]	—	—	—	—	—	
	Mean	**16·05**	**16·38**	**19·78**	**29·08**	**0·811**	**0·828**	**0·552**	**0·326**	**30,670,000**	
278–1	$\frac{15}{16}$	17·28	18·72	20·70	30·34	0·835	0·904	0·569	0·315	31,750,000	
278–2	,,	15·47	16·20	20·63	30·94	0·750	0·785	0·500	0·336	29,790,000	
278–3	,,	14·98	17·98	20·63	30·90	0·726	0·872	0·485	0·323	30,950,000	
	Mean	**15·89**	**17·63**	**20·65**	**30·73**	**0·769**	**0·854**	**0·517**	**0·325**	**30,770,000**	
279–1	$1\frac{1}{16}$	—	[19·63]	[21·70]	[26·91]	—	[0·905]	—	—	—	
279–2	,,	16·73	19·37	21·31	27·12	0·785	0·909	0·617	0·329	30,420,000	
279–3	,,	12·88	12·88	20·87	28·35	0·617	0·617	0·454	0·323	30,930,000	
	Mean	**14·80**	**16·12**	**21·09**	**27·73**	**0·702**	**0·764**	**0·534**	**0·326**	**30,675,000**	
Mean of 7 complete expts.		**15·63**	**16·84**	**20·53**	**29·40**	**0·762**	**0·821**	**0·533**	**0·326**	**30,670,000**	

RIVETED JOINTS.—TABLE XI.

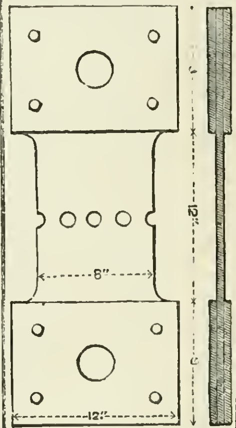
SERIES IV.—GENERAL RESULTS.—(*Shearing Strength of Rivet Steel.*)

Test Number.	Original Diameter of Bar. (Nominal) In.	Tested Diameter. In.	Shearing Load. Pounds per sq. in.	Shearing Load. Tons per sq. in.	Tenacity of same material. Tons per sq. in.	Ratio of Shearing to Tensile Resistance. Per cent.	Remarks.
343	$1\frac{1}{16}$	1·000	54,110	24·15			
344	,,	1·000	54,930	24·52			
345	,,	0·998	55,240	24·66			
346	,,	1·000	52,830	23·59			
347	,,	1·001	56,660	25·29			
348	,,	1·000	53,530	23·90			
349	,,	1·000	—	—			Removed for inspection after application of 12,000 lbs.= 5·36 tons per sq. in.
350	,,	1·000	—	—			Do. do. 45,000 lbs.=20·1 ,,
		Mean...	54,550	24·35	27·46	88·7	
278–1	$\frac{15}{16}$	0·620	60,260	26·90			These pieces were cut from the unstrained ends of the similarly numbered specimens of Series III., Table VIII.
278–1	,,	0·620	59,400	26·52			
278–2	,,	0·620	59,600	26·61			
278–2	,,	0·622	59,220	26·44			
278–3	,,	0·621	59,740	26·67			
		Mean...	59,640	26·63	30·73	86·7	
741-1	$\frac{11}{16}$	0·621	53,670	23·96			
741-2	,,	0·621	51,290	22·90			
741-3	,,	0·621	52,670	23·51			
741-4	,,	0 623	53,000	23·66			
741-5	,,	0·623	51,620	23·04			
		Mean...	52,450	23·41	29·17	80·3	
		Mean...	**55,550**	**24·80**	**29·12**	**85·2**	

RIVETED JOINTS.—TABLE XII.

SERIES V.—GENERAL RESULTS.—(*Steel Boiler Plate, with Punched and Drilled Holes.*)

Test No.	Description.	Mean Thickness of Plate. In.	Mean Pitch of Holes. In.	Mean Diameter of Holes. In.	Tenacity in Tons per sq. in. net section. Widths as under:— Two Inches.	Four Inches.	Six Inches.	Eight Inches.	Mean Tenacity. Tons per sq. in.	Tenacity as compared with that of Solid plate.	Drilled plate.	Remarks.
322–1 to 4	$\frac{1}{4}$ plate, drilled holes	0·263	2·00	0·940	36·72	37·92	39·93	37·90	38·12	1·105		Below is sketch of widest specimen. Those with fewer holes are similarly arranged.
323–1 to 4	,, ,, ,,	0·261	2·00	0·940	37·33	37·92	39·52	38·10	38·22	1·108		
	Mean				**37·02**	**37·92**	**39·72**	**38·00**	**38·17**	**1·107**	**1·000**	
324–1 to 4	$\frac{1}{4}$ plate, $\frac{7}{8}$ punch, $\frac{31}{32}$ die	0·259	2·00	·912–·876	35·65	35·41	34·38	34·71	35·04	1·000	0·918	
325–1 to 4	,, ,, $\frac{29}{32}$ die	0·259	2·00	·892–·871	36·21	33·72	33·38	34·46	34·44	1·025	0·902	
	Mean				**35·93**	**34·56**	**33·88**	**34·58**	**34·74**	**1·012**	**0·910**	
326–1 to 4	$\frac{3}{8}$ plate, drilled holes	0·365	2·00	0·926	36·07	35·18	35·40	34·90	35·39	1·126		
327–1 to 4	,, ,, ,,	0·366	2·01	0·934	35·28	34·86	33·97	35·50	34·90	1·111		
	Mean				**35·67**	**35·07**	**34·68**	**35·20**	**35·15**	**1·119**	**1·000**	
328–1 to 4	$\frac{3}{8}$ plate, $\frac{7}{8}$ punch, 1 die	0·363	2·01	·998–·890	33·48	34·60	33·36	34·21	33·91	1·073	0·965	
329–1 to 4	,, ,, $\frac{15}{16}$ die	0·360	2·02	·945–·875	35·19	34·24	33·71	34·31	34·38	1·096	0·978	
	Mean				**34·33**	**34·42**	**33·55**	**34·27**	**34·14**	**1·084**	**0·971**	



RIVETED JOINTS.—TABLE XIII.

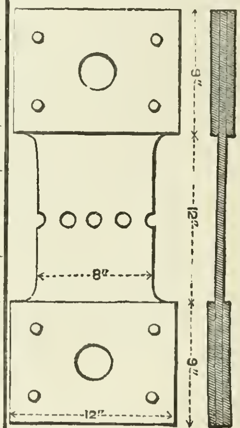
Series V.—Tenacity of Plates used.

Test No.	Dimensions.			Limit of Elasticity.		Breaking Load.		Ratio of Limit to Breaking Load.	Per cent. of Extension in 4 in.	No. of Corresponding Specimens in Table XII.	Nature of Fracture, &c.
	Breadth. In.	Thickness. In.	Area. Sq. In.	Pounds per sq. in.	Tons per sq. in.	Pounds per sq. in.	Tons per sq. in.				
368–1	0·975	0·260	0·253	49570	22·13	77270	34·50	0·641	26·5	322 & 3	Some lamination near surface.
368–2	0·975	0·260	0·253	49400	22·05	77270	34·50	0·639	20·7		
			Mean	**49485**	**22·09**	**77270**	**34·50**	**0·640**	**23·6**		
368–3	0·975	0·258	0·251	50800	22·68	75300	33·61	0·675	24·2	325	Very distinct longitudinal splitting.
368–4	0·975	0·260	0·253	50690	22·63	78550	35·06	0·645	25·5	324	
			Mean	**50745**	**22·65**	**76925**	**34·33**	**0·660**	**24·8**		
369–1	0·977	0·357	0·349	43350	19·35	71060	31·73	0·610	29·5	326 & 7	
369–2	0·977	0·357	0·349	42620	19·03	69690	31·11	0·612	30·2		
			Mean	**42985**	**19·19**	**70375**	**31·42**	**0·611**	**29·8**		
369–3	0·974	0·364	0·351	43730	19·52	70800	31·61	0·618	22·5	329	Some longitudinal splitting. Central line very much distorted.
369–4	0·977	0·362	0·354	42590	19·01	70260	31·37	0·606	22·5	328	
			Mean	**43160**	**19·27**	**70530**	**31·49**	**0·612**	**22·5**		

RIVETED JOINTS.—TABLE XIV.

Series Va.—General Results.—(*Steel Boiler Plates, with Punched and Drilled Holes.*)

Test Number.	Description. Dimensions in inches.	Mean Thickness of Plate. In.	Mean Pitch of Holes. In.	Mean Diameter of Holes. In.	Tenacity in Tons per sq. in. net section. Widths as under:— Two Inches.	Four Inches.	Six Inches.	Eight Inches.	Mean Tenacity. Tons per sq. in.	Tenacity as compared with Solid plate.	Drilled holes.	Remarks.
454–1 to 4	$\frac{1}{4}$ plate, drilled holes	0·264	1·99	0·947	33·58	32·79	32·67	32·93	32·99	1·137		Below is sketch of widest specimen. The rest similarly arranged.
455–1 to 4	,, ,, ,,	0·268	1·99	0·911	33·09	32·21	32·28	28·62	31·54	1·087		
	Mean				**33·33**	**32·50**	**32·47**	**30·77**	**32·26**	**1·112**	**1·000**	
456–1 to 4	$\frac{1}{4}$ plate, $\frac{7}{8}$ punch, $\frac{31}{32}$ die	0·263	2·00	·869–·912	29·28	31·12	30·92	31·55	30·72	1·059		
457–1 to 4	,, ,, $\frac{29}{32}$ die	0·263	1·99	·889–·904	30·92	29·67	30·32	33·23	31·03	1·070		
	Mean				**30·10**	**30·39**	**30·62**	**32·39**	**30·87**	**1·064**	**0·957**	
458–1 to 4	$\frac{3}{8}$ plate, drilled holes	0·380	1·99	0·934	32·00	30·86	31·97	31·65	31·62	1·095		
459–1 to 4	,, ,, ,,	0·380	1·98	0·932	32·90	32·24	32·05	32·35	32·38	1·122		
	Mean				**32·45**	**31·55**	**32·01**	**32·00**	**32·00**	**1·108**	**1·000**	
460–1 to 4	$\frac{3}{8}$ plate, $\frac{7}{8}$ punch, 1 die	0·378	2·00	·867–·981	30·40	30·28	30·80	31·36	30·71	1·064	0·960	
461–1 to 4	,, ,, $\frac{15}{16}$ die	0·378	2·00	·870–·931	31·36	30·08	29·37	30·61	30·35	1·051	0·948	
	Mean				**30·88**	**30·18**	**30·08**	**30·98**	**30·53**	**1·058**	**0·954**	



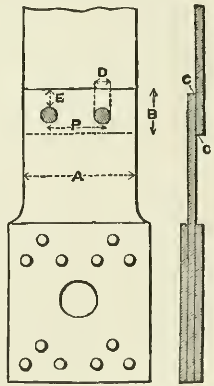
RIVETED JOINTS.—TABLE XV.

Series Va.—Tenacity of Plates used.

Test No.	Dimensions. Breadth. In.	Dimensions. Thickness. In.	Dimensions. Area. sq. in.	Limit of Elasticity. Pounds per sq. in.	Limit of Elasticity. Tons per sq. in.	Breaking Load. Pounds per sq. in.	Breaking Load. Tons per sq. in.	Ratio of Limit to Breaking Load.	Percentage of Elongation in 4 in.	Remarks.
464	0·994	0·271	0·269	43130	19·25	65280	29·14	0·661	28·2	Tested as received.
571–1	0·999	0·265	0·265	44720	19·96	65660	29·31	0·681	28·7	Cut from unstrained part of No. 456–4.
571–2	0·997	0·269	0·268	45900	20·49	65040	29·04	0·706	29·2	
571–3	0·997	0·269	0·268	46680	20·84	64820	28·94	0·720	29·0	
571–4	0·996	0·270	0·269	45500	20·31	65240	29·13	0·697	30·2	
572–1	0·996	0·270	0·269	45620	20·36	64360	28·73	0·709	28·7	Cut from unstrained part of No. 454–4.
572–2	0·998	0·271	0·270	44770	19·99	64780	28·92	0·691	29·7	
572–3	0·997	0·272	0·271	45500	20·31	64760	28·91	0·703	29·0	
572–4	0·996	0·271	0·270	45670	20·39	64780	28·92	0·705	29·5	
			Mean	**45280**	**20·21**	**64970**	**29·00**	**0·697**	**29·1**	
465	0·994	0·384	0·382	41890	18·70	64860	28·96	0·646	28·5	Tested as received.
573–1	1·000	0·383	0·383	40580	18·12	63840	28·51	0·636	29·7	Cut from unstrained part of No. 458–3.
573–2	0·998	0·383	0·382	41390	18·48	64170	28·65	0·645	29·5	
573–3	0·996	0·381	0·380	42480	18·96	64430	28·76	0·659	28·2	
574–1	0·997	0·384	0·383	41360	18·47	64870	28·96	0·638	28·5	Cut from unstrained part of No. 460–3.
574–2	0·997	0·383	0·382	41620	18·58	65200	29·11	0·638	27·2	
574–3	0·996	0·382	0·381	43320	19·34	65120	29·07	0·665	28·5	
			Mean	**41810**	**18·66**	**64640**	**28·87**	**0·647**	**28·6**	

RIVETED JOINTS.—TABLE XVI.

MEASUREMENTS OF SERIES VI.—(*First Series of Riveted Joints.*)

Test No.	Original No. in Series.	Nominal Dimensions. In.	Dimensions by Actual Measurement. A. (width) In.	B. (lap) In.	C. (thickness) In.	Dimensions assumed correct. D. (diameter of rivet) In.	E. (margin) In.	P. (pitch) In.	Size to which holes were drilled.	Joint intended to break by	Ratio of Shearing to Tearing area.	Ratio of Bearing to Tearing area.	Remarks, &c.
377	1	$\frac{3}{8}$ plate, $\frac{1}{2}$ rivets	1·76	1·80	0·370	0·50	0·625	0·875	0·531	Tearing	1·76	1·56	Sketch below shows the dimension corresponding to the Reference letters at head of columns. Two rivets in all cases. 
378	1	,,	1·73	1·86	0·369	,,	,,	,,	,,	,,			
379	4	,,	1·99	1·91	0·365	,,	,,	1·00	,,	Shearing	1·29	1·13	
380	4	,,	2·01	1·83	0·367	,,	,,	,,	,,	,,			
381	2	$\frac{3}{8}$ plate, $\frac{3}{4}$ rivets	3·00	2·86	0·379	0·75	1·000	1·50	0·781	Tearing	1·76	1·09	
382	2	,,	2·99	2·82	0·378	,,	,,	,,	,,	,,			
383	5	,,	3·98	2·87	0·377	,,	,,	2·00	,,	Shearing	1·06	0·65	
384	5	,,	3·96	2·79	0·375	,,	,,	,,	,,	,,			
385	3	$\frac{3}{8}$ plate, 1 rivets	4·51	3·67	0·387	1·00	1·25	2·25	1·03	Tearing	1·78	0·84	
386	3	,,	4·50	3·68	0·382	,,	,,	,,	,,	,,			
387	6	,,	6·01	3·65	0·386	,,	,,	3·00	,,	Shearing	1·09	0·52	
388	6	,,	6·01	3·60	0·388	,,	,,	,,	,,	,,			

RIVETED JOINTS.—TABLE XVII.

For Tenacity, see Table XVIII.

SERIES VI.—GENERAL RESULTS.—(*First Series of Riveted Joints.*)

For Dimensions, see Table XVI.

	Test Number.	Tearing Area.	Tensile stress when joint broke.		Shearing Area.	Shearing stress when joint broke.		Bearing Area.	Bearing pressure when joint broke.		Joint intended to break by	Broke by	Breaking Load per inch breadth of:—		Proportional Strength of Joint.
		sq. in.	Pounds per sq. in.	Tons per sq. in.	Sq. In.	Pounds per sq. in.	Tons per sq. in.	sq. in.	Pounds per sq. in.	Tons per sq. in.			Joint. Tons.	Solid Plate. Tons.	per cent.
$\frac{1}{2}$ in. rivets.	377	0·258	62480	27·90	0·444	36300	16·20	0·393	41020	18·31	Tearing	Tearing			
	378	0·246	71640	31·98	,,	39680	17·72	0·392	44950	20·07	,,	,,			
	Mean		**67060**	**29·94**		**37990**	**16·96**		**42980**	**19·19**			4·32	11·07	39·3
	379	0·338	63600	28·40	,,	48420	21·62	0·388	55400	24·73	Shearing	Tearing			
	380	0·348	67020	29·92	,,	52530	23·45	0·390	59810	26·70	,,	,,			
	Mean		**65310**	**29·16**		**50475**	**22·53**		**57600**	**25·71**			5·00	10·97	45·6
$\frac{3}{4}$ in. rivets.	381	0·547	76410	34·11	0·958	43620	19·47	0·592	70600	31·52	Tearing	Tearing			
	382	0·540	77690	34·68	,,	43790	19·55	0·590	71100	31·74	,,	,,			
	Mean		**77050**	**34·40**		**43700**	**19·51**		**70850**	**31·63**			6·23	11·34	55·0
	383	0·905	57540	25·68	,,	54360	24·27	0·589	88400	39·47	Shearing	Shearing			
	384	0·898	58190	25·98	,,	54560	24·36	0·586	89160	39·81	,,	,,			
	Mean		**57870**	**25·83**		**54460**	**24·31**		**88780**	**39·64**			5·87	11·27	52·1
1 in. rivets.	385	0·948	64810	28·93	1·67	36790	16·42	0·798	77000	34·37	Tearing	Shearing			
	386	0·932	67540	30·15	,,	37700	16·83	0·788	79890	35·66	,,	,,			
	Mean		**66170**	**29·54**		**37240**	**16·63**		**78440**	**35·01**			6·16	11·52	53·5
	387	1·524	43510	19·42	,,	39710	17·73	0·796	83310	37·19	Shearing	Shearing			
	388	1·531	41170	18·38	,,	37740	16·85	0·800	78800	35·17	,,	,,			
	Mean		**42340**	**18·90**		**38720**	**17·29**		**81050**	**36·18**			4·80	11·60	41·6

It has been assumed in these calculations that the Rivet actually filled up the hole which had been drilled for it.

RIVETED JOINTS.—TABLE XVIII.

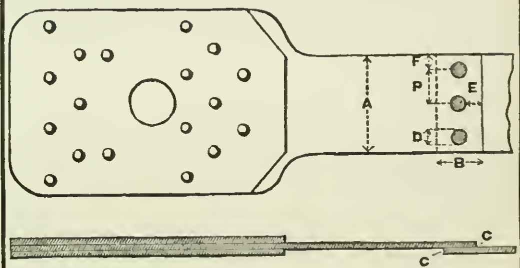
Series VI.—Tenacity of Plates used.

Test No.	Dimensions.			Limit of Elasticity.		Breaking Load.		Ratio of Limit to Breaking Load.	Per cent. of extension in 4 in.	Nature of Fracture, &c.
	Breadth. In.	Thickness. In.	Area. sq. in.	Pounds per sq. in.	Tons per sq. in.	Pounds per sq. in.	Tons per sq. in.			
462–1	2·002	0·369	0·738	39640	17·70	66400	29·64	0·597	31·0	
462–2	1·998	0·383	0·765	40060	17·88	66860	29·85	0·599	25·7	
472–1	1·019	0·373	0·380	42240	18·86	68450	30·56	0·617	26·5	Fracture somewhat obliquely across.
472–3	1·747	0·380	0·664	44430	19·84	67100	29·96	0·662	24·3 (in 6 in.)	Fracture irregularly across.
472–4	1·745	0·385	0·672	40470	18·07	66820	29·83	0·606	27·3 (in 6 in.)	Fracture very irregularly across.
			Mean	**41368**	**18·47**	**67130**	**29·97**	**0·616**		

RIVETED JOINTS.—TABLE XIX.

Measurements of Series VII.—(*Second Series of Riveted Joints; varied for Margin and Pitch.*)

Test No.	Original No.	A. (width) In.	B. (lap) In.	C. (thickness) In.	Nominal Dimensions. E. (margin) In.	Nominal Dimensions. P. (pitch) In.	Nominal Diameter of Drilled Holes. In.	Ratio of Shearing to Tearing area.	Ratio of Bearing to Tearing area.	Remarks.
				Mean.						
431	2	4·807	2·82	**0·366**	1·00	1·61	0·781 $\left(\frac{3}{4}+\frac{1}{32}\right)$	1·59	0·95	Form of specimen as sketch below. All specimens have the same diameter and number of Rivets. Nos. 431, 432, and 433 have the same pitch, but different margins; Nos. 434, 435, and 436 have the same margin but different pitches. In all cases F=0·80; and nominal diameter of rivet is 0·75.
432	1	4·810	2·63	**0·378**	0·875	,,	,,	1·54	0·95	
433	3	4·806	2·36	**0·386**	0·75	,,	,,	1·51	0·95	
434	4	5·000	2·33	**0·372**	0·75	1·70	,,	1·45	0·88	
435	5	5·135	2·31	**0·377**	0·75	1·78	,,	1·37	0·84	
436	6	5·597	2·31	**0·368**	0·75	2·00	,,	1·20	0·72	



For Tenacity, see Table XXI.

RIVETED JOINTS.—TABLE XX.

SERIES VII.—GENERAL RESULTS.—(*Second Series of Riveted Joints; varied for Margin and Pitch.*)

For Dimensions, see Table XIX.

Test No.	Tearing Area.	Tensile stress when joint broke.		Shearing Area.	Shearing stress when joint broke.		Bearing Area.	Bearing pressure when joint broke.		Joint broke by	Breaking Load. Per in. run.		Proportional strength of Joint.	Remarks.
	sq. in.	Pounds per sq. in.	Tons per sq. in.	sq. in.	Pounds per sq. in.	Tons per sq. in.	sq. in.	Pounds per sq. in.	Tons per sq. in.		Joint. Tons.	Solid Plate. Tons.	Per cent.	
431	0·902	78040	34·84	1·437	48990	21·87	0·858	82060	36·63	Shearing	6·54	11·0	59·7	It has been assumed in making the calculations that the Rivet actually filled up the hole (0·781 diameter) which was drilled in the plate for it.
432	0·932	76510	34·15	,,	49650	22·16	0·886	80500	35·94	,,	6·62	11·3	58·6	
433	0·950	74540	33·28	,,	49270	22·00	0·905	78240	34·92	,,	6·58	11·5	57·0	
	Mean	**76360**	**34·09**	—	**49300**	**22·01**	—	**80270**	**35·83**	,,				
434	0·988	71180	31·78	,,	48930	21·85	0·872	80640	36·00	,,	6·28	11·1	56·5	
435	1·052	64530	28·81	,,	47240	21·09	0·884	76780	34·28	,,	5·90	11·3	52·4	
436	1·197	56940	25·42	,,	47440	21·17	0·863	78980	35·26	,,	5·44	11·0	49·4	
	Mean	**64220**	**28·67**	—	**47870**	**21·37**	—	**78800**	**35·18**					

RIVETED JOINTS.—TABLE XXI.

Series VII.—Tenacity of Plates used.

Test No.	Dimensions. Breadth. In.	Thickness. In.	Area. Sq. In.	Limit of Elasticity. Drop of Steelyard. Pounds per sq. in.	Tons per sq. in.	Breaking Load. Pounds per sq. in.	Tons per sq. in.	Ratio of Limit to Breaking Load.	Extension in 4 in. Per cent.	Nature of Fracture, &c.
463–1	2·002	0·382	0·765	39480	17·62	66790	29·82	0·591	23·2	
463–2	1·998	0·368	0·735	42850	19·13	67340	30·06	0·636	28·4	
473–3	1·756	0·377	0·662	32860	14·67	66850	29·84	0·492	27·5 (in 6 in.)	Fracture obliquely across. Some longitudinal splitting.
473–4	1·744	0·370	0·645	38380	17·13	66980	29·91	0·573	28·0 (do.)	
			Mean	**38390**	**17·14**	**66990**	**29·91**	**0·573**		

RIVETED JOINTS.—TABLE XXII.

Measurements of Series VIII.—(*Final Series of Riveted Joints.*)

Test Number.	Total Breadth.	Diameter of Drilled Holes.	Pitch of Holes.	Thickness of Plate.	Ratio of Shearing to Tearing Area.	Ratio of Bearing to Tearing Area.	Remarks.
	In.	In.	In.	In.			
652–1 to 3	11·34	0·79	1·62	0·400	1·46	0·94	Ends made similarly to those in Series VII. Seven rivets in each joint.
653–1 to 3	11·84	0·86	1·68	0·399	1·75	1·03	
654–1 to 3	10·90	0·75	1·56	0·401	1·36	0·93	
655–1 to 3	12·20	0·78	1·74	0·386	1·34	0·83	
656–1 to 3	10·45	0·78	1·49	0·393	1·72	1·10	
657–1 to 3	12·32	0·79	1·77	0·347	1·47	0·82	

For Tenacity, see Table XXIV.

RIVETED JOINTS.—TABLE XXIII.

SERIES VIII.—GENERAL RESULTS.—(*Final Series of Riveted Joints.*)

For Dimensions, see Table XXII.

Test Number.	Tearing Area.	Tensile Stress when joint broke.		Shearing Area.	Shearing Stress when joint broke.		Bearing Area.	Bearing Pressure when joint broke.		Proportion of Breaking Load at which visible slip occurred.	Joint broke by :—	Breaking Load per inch breadth of		Proportional Strength of Joint.
	Sq. In.	Pounds per sq. in.	Tons per sq. in.	Sq. In.	Pounds per sq. in.	Tons per sq. in.	sq. in.	Pounds per sq. in.	Tons per sq. in.	Per cent.		Joint. Tons.	Solid Plate. Tons.	Per cent. of solid plate.
652–1 to 3	2·337	70240	31·36	3·417	48030	21·46	2·209	74300	33·17	19·3	Shearing	6·46	11·73	55·1
653–1 to 3	2·320	73030	32·60	4·064	41690	18·61	2·402	70520	31·49	25·2	Two shorn, One torn	6·41	11·70	54·8
654–1 to 3	2·270	69420	30·99	3·080	51170	22·84	2·103	74950	33·46	21·9	Shearing	6·45	11·76	54·9
655–1 to 3	2·572	66190	29·54	3·440	49450	22·08	2·137	79660	35·56	20·4	Shearing	6·22	11·32	54·9
656–1 to 3	1·956	80920	36·13	3·371	46950	20·96	2·156	73420	32·78	27·0	Two torn, One shorn	6·76	11·52	58·6
657–1 to 3	2·347	72930	32·56	3·452	49480	22·09	1·924	88950	39·71	27·0	Shearing	6·19	10·18	60·8
Highest Single Result.														
657–2	2·212	76220	34·03	3·442	48980	21·87	1·811	93100	41·56	24·0	Shearing	6·11	9·59	63·7

RIVETED JOINTS.—TABLE XXIV.

SERIES VIII.—TENACITY OF PLATES USED.

Test No.	Dimensions.			Limit of Elasticity. Drop of Steelyard.		Breaking Load.		Ratio of Limit to Breaking Load.	Percentage of Final Extension.		Remarks.
	Breadth.	Thickness.	Area.	Pounds per sq. in.	Tons per sq. in.	Pounds per sq. in.	Tons per sq. in.		In 2 in. at fracture.	In total length of 10 in.	
	In.	In.	Sq. In.						Per cent.	Per cent.	
652	1·754	0·396	0·695	35460	15·82	66450	29·66	0·533	38	23·6	The numbers of these specimens correspond with the numbers of the plates in Series VIII. (see Tables XXII. and XXIII.) from which they were cut.
652	1·750	0·409	0·716	40620	18·13	67100	29·95	0·605	45	23·6	
653	1·760	0·410	0·722	35210	15·72	63630	28·40	0·554	42	18·9	
653	1·751	0·409	0·716	40870	18·24	66850	29·84	0·611	40	23·8	
654	1·752	0·403	0·706	41360	18·46	67380	30·08	0·614	45	22·9	
654	1·757	0·405	0·712	38710	17·28	64950	29·00	0·596	45	23·8	
655	1·756	0·410	0·720	40470	18·07	66720	29·79	0·607	42	21·8	
655	1·753	0·371	0·650	37080	16·55	60150	26·85	0·616	46	24·1	
656	1·741	0·407	0·709	40340	18·01	67000	29·91	0·602	43	21·8	
656	1·755	0·407	0·714	35780	15·97	64690	28·88	0·553	45	21·9	
657	1·756	0·325	0·571	40950	18·28	65850	29·40	0·622	47	24·1	
657	1·760	0·326	0·574	43660	19·49	67500	30·14	0·647	44	24·1	
657	1·755	0·327	0·574	41990	18·75	65820	29·38	0·638	51	27·1	
			Means	**39430**	**17·60**	**65700**	**29·33**	**0·600**	**44·1**	**23·2**	

RIVETED JOINTS.—TABLE XXV.

SERIES VIII.—*Shearing Strength of Rivet Steel used.*

Test Number.	Original Diameter of Bar (nominal) In.	Tested Diameter In.	Shearing Load. Pounds per sq. in.	Shearing Load. Tons per sq. in.	Remarks.
728–1	$\frac{3}{4}$	0·621	57230	25·55	
728–2	,,	0·621	58880	26·28	
728–3	,,	0·621	58950	26·32	All these specimens showed signs of passing a Limit of Elasticity at points varying from 58 per cent. to 85 per cent. (mean 70·3 per cent.) of their breaking load.
728–4	,,	0·621	58950	26·32	A piece cut from the same bar and tested for tenacity had its limit at 18·62 tons per sq. in., and broke at 29·03 tons per sq. in. The
728–5	,,	0·621	60270	26·91	ratio of shearing to tensile resistance is therefore in this case $\frac{26·33}{29·03}$,
728–6	,,	0·621	59600	26·61	or nearly 91 per cent.
		Means	58980	26·33	

NOTE.

Since the paper was read it has been pointed out to the author by Professor Unwin that without a little further explanation the formula given on page 229 may be somewhat misleading. The first of the two equations given (viz. $1 \cdot 47\,(p - d)\,t = \frac{\pi}{4} d^2$) is the equation which comes directly out from the experiments, and this equation gives an absolute relation which the pitch ought to bear to the diameter of the rivet whatever that diameter may be, this relation being $p = 0 \cdot 53\,\frac{d^2}{t} + d$. This formula may always be used in cases of material and joints similar to those experimented upon, where both thickness of plate and diameter of rivet are fixed beforehand, and will give the best pitch for the given diameter of rivet. From the same equation however there can be obtained the relative strength of the joint and solid plate (neglecting, as a constant, the increase of strength by perforation), as follows:—

$$\frac{\text{net plate}}{\text{gross plate}} = \frac{p - d}{p} = 0 \cdot 53\,\frac{d^2}{pt} = 0 \cdot 53\,\frac{d}{p} \times \frac{d}{t}$$

Therefore for any given ratio of diameter to pitch $\left(\frac{d}{p}\right)$ the strength of the joint increases in proportion to the ratio of diameter to thickness. If the allowable bearing pressure be fixed beforehand, this ratio $\left(\frac{d}{t}\right)$ is also fixed, as the equations show. The larger this ratio (other things being equal), the greater the intensity of pressure on the rivet. The proportion $d = 2 \cdot 28\,t$ corresponds to a pressure of about 40 tons per sq. in.; it may quite well be that further experiments will show a much higher pressure to be available. in which case a larger rivet might be used, and a greater strength obtained. But practical considerations would seldom allow a larger rivet to be used, and as plates become thicker they compel the use of a much smaller ratio of diameter to thickness. Hence for ordinary circumstances it may be said that to obtain the strongest single-riveted joint the rivets should be made as large as is practicable, and the pitch proportioned as given in this note. If the rivet diameter is less than $2\frac{1}{4}$ times the thickness of the plate, the strength of the joint will inevitably be less than the strength of No. 657, although it may be the strongest possible joint with the given diameter of rivet. Professor Unwin points out that in double and treble-riveted joints the proportionate loss of strength due to the use of too small rivets is very much less than in single-riveted joints—a point of great importance in many cases, and especially in heavy boiler-work.

Discussion on Riveted Joints.

Professor Kennedy desired to say one or two words. He wished, in the first place, to apologise for the length of his paper; but it had to be put in the nature of a statement of results for the Institution, and he was therefore bound to make it as complete as possible. In the next place he wished to mention a suggestion of his friend Mr. Willis, to whom he had been indebted for a good deal of help during the experiments:—namely, that the actual shearing resistance of the rivet in the plate, independently of the complication introduced by the bending of the plate, could be easily tested in the shearing apparatus. The method was simply to take two pieces of plate, rivet them together, cut out the part of the plates where the rivets were, in the form of discs with the rivets in the centre, put these into the apparatus and shear them dead fair. The shearing was thus accomplished without any bending outward. They had just been able to carry out these experiments, and Mr. Willis informed him that the shearing resistance came to $27\frac{1}{2}$ tons per sq. in.; which was 27 per cent. more than the average resistance of the same sized rivets when tested in the joints, and about 4 per cent. more than the natural average resistance of the same steel before it was made into the rivet. The rivets used were some which Mr. Boyd had been kind enough to send him, and were from the identical bars which had been used in Series VIII. The plates were also from Series VIII. Some of the shorn rivets were on the table.

Mr. R. H. Tweddell said that at the request of the Committee on Riveted Joints he had laid before its members the appended Table (pp. 293–299), giving the practice of several leading authorities as to the dimensions of riveted joints for different thicknesses of plate. His object in proposing the compilation of this Table to his colleagues on the Committee was simply that they might avail themselves of the experience gained in actual practice by the manufacturers of this country. The theoretical aspect of the question of riveted joints

had been so ably dealt with by other gentlemen, and especially in the two papers brought before the members on this occasion, that he might be excused if he confined himself to results shown in workshop practice. For the slight contribution which he had thus made towards the elucidation of this subject he was indebted to the information kindly supplied by various firms, who were represented by the letters placed at the top of the columns. The general result of the information he had received (and he should be very glad if, before the final conclusion of the enquiry, any other gentlemen or firms would furnish similar data) was to show a great variation in the practice of boiler-makers in this country, and consequently a great variation in the strength of the joints designed by them. For greater clearness, he had worked out roughly the strength of the rivets and also of the plate in each joint, as a percentage of the strength of the solid plate. These figures were given in the Table, and the maximum and minimum results were also given in the diagram, Plate 33. That diagram showed at a glance how wide the variations were in practice; and also how, even with the best practice, the proportion of strength steadily declined as the plate was increased in thickness.

Turning to Professor Kennedy's paper, there was one point which he thought of the very greatest importance, namely the question of the "elastic life" of the material. That investigation seemed to him to be a most important, and in some respects a rather startling one. It appeared that a set distinctly commenced at a load of 8·2 tons per sq. in., in a material which was capable of standing a stress of about 30 tons. If so, it would seem necessary to increase considerably the margin of safety with which engineers were now working in many of their structures.

In reference to the question which had been raised on p. 210, as to substituting some new term for " what is called commercially the limit of elasticity," he would suggest that Professor Kennedy himself had on p. 211 given an indication as to what this term should be, where he spoke of " a change which is perhaps best described by the phrase *breaking down*." He (Mr. Tweddell) would suggest that the stage in the experiments where the set curve was first distinctly

marked would be accurately described by the term "limit of fatigue," this being the point where it might be said that exhaustion had ensued, or a condition just previous to breaking down. He merely threw out the suggestion, as it occurred to him in reading Professor Kennedy's remarks on the subject.

Professor Kennedy had also alluded to the question of "margin and pitch." One of the objects of compiling the Table he had presented was to discover the largest margin, and also the widest pitch, which could be given consistent with fair caulking. Of course a large margin gave an increased leverage to the caulking tool, tending to open the joint. In his own opinion however caulking was a barbarous process, and not at all necessary, if a joint was properly made and riveted to begin with. He believed that caulking, as formerly understood, was not now used in any good boiler shop. Fullering up, or simply closing up the joint with a light hammer and a small tool, was of course admissible; but that did not involve any strain on the rivets. Further, the result of Professor Kennedy's observations showed that a reduction of the margin to about the diameter of the rivet did not materially affect the strength of the joint; and the Tables showed that, with double riveting, a pitch of $4\frac{1}{2}$ diameters could be used in practice, which was also stated in Baron Clauzel's paper (p. 190) as being the French practice. Therefore he thought that a step had been made in advance, in their knowledge of riveted joints, when it was shown not to be necessary for the strength of the joint to give a large margin; and this, coupled with the fact that a good pitch was admissible, owing to the non-necessity for caulking, gave at once the elements of a good and economical joint.

Mr. F. W. Webb said that his experience in riveting was mainly of a practical character, and he had no time now for making any further theoretical experiments, but he should like to say a few words. First, with regard to caulking, Figs. 15 and 16, Plate 32, illustrated the method he adopted. Instead of caulking at all at the very edge of the plate, he bevelled the edge, and used a fuller or caulking tool F, made in the shape shown, so as to have no tendency to separate the

two thicknesses of plate. Another point with regard to his practice, which he had spoken of before (Proceedings 1879, p. 305), and which saved in great measure the necessity of caulking, was that he always sponged the two inside surfaces of a joint with hot water and sal ammoniac, to eat off the magnetic oxide, before putting the plates together. Unless this were done, the oxide would generally get hammered off in some places and left on in others: and, where it was left on, it got pounded to powder in the act of riveting, and was so left between the plates; in which case the steam got in and cut away the joint. But the sponging of the two surfaces with sal ammoniac took the oxide entirely away; and his boilers were practically tight at 160 lbs. pressure when they came out of the shop, without anything further being done.

There was a remark in Baron Clauzel's paper, p. 201, to the effect that the corrosion in ships was outside, and that the corrosion in boilers was inside. That however was not what he found in practice. In the steamers of the London and North Western Railway Co., at all events, the great trouble was, in carrying cattle, to prevent corrosion inside. What with the urine of the cattle getting on the plates, and the Board of Trade insisting that they should be lime-washed, their ships were rapidly corroding away. Again, he had found both in iron and steel boilers that the slightest weeping at the joints would cut out a plate very rapidly, in the form shown in Fig. 14. He had seen a plate cut half way through in six months, especially round the front angle-irons of a locomotive boiler. That had led him to use a very much wider flange for the angle-iron in locomotive boilers, as in Figs. 12 and 13, Plate 32, and to make the inner rivets at A $\frac{13}{16}$ in. diam. and the outer rivets at B only $\frac{5}{8}$ in. or $\frac{11}{16}$ in. This had given a very much better result than he had hitherto obtained. He had previously found in practice that the weakening of the plate, by the rivets which united it to the short stiff angle-iron, caused it to bend, and gradually to corrode all the way round, as shown at C, Figs. 10 and 11. By softening off the thickness of the angle-iron a little more, and putting smaller rivets towards its edge, that was prevented, so that the plates did not now corrode there, and there was no trouble with leaky joints arising

from the leverage of the angle-iron working on the weakest point of the plate. At the present time he had over 1600 locomotive boilers of steel, working at 140 to 145 lbs. per sq. in., and he had had no trouble whatever with them.

In reference to steel, he might be allowed to mention that down to the present time he had made over 100,000 practical tests on steel plates, and had never had to reject more than two plates for failing in actual work; and those two cases had been entirely due to mismanagement on the part of the men. Some little time ago he had a plate sent to him from one of the boilers that had failed in the case of the *Livadia*, a circumstance which had caused a great deal of sensation. He was rather surprised to find that the examination of this plate did not reveal what had caused the failure; but having recently learnt the way in which the plates had been treated, he was no longer surprised that they failed. In his opinion they had been as ill-treated as any material could possibly be, both in the so-called annealing, and in the method of bending the plates. The idea of bending plates hot in rolls astonished him. If they would not stand bending cold, it would be better to send them to scrap at once. In the case of the piece sent to him from one of the fractured plates, he cut it in two, put one half aside as he had received it, and sent the other half into the shops without letting the men know where it came from, merely saying, "Treat that plate as you treat ours." The result was, after they had annealed the plate in the usual way—which was practically nothing else than putting all the particles of the plate at rest, without any softening off, or covering up with sawdust or sand &c.—they punched a $\frac{5}{8}$-in. hole in a strip $3\frac{1}{4}$ in. wide, and then drove a 2-in. drift right through the plate cold, without fracture. He then had the other half bent double while cold, and that although it still showed a fractured edge, just as it was cut out of the boiler. He thought those tests showed that it was the way in which the plates had been dealt with, both in attempting to anneal them and in the manufacture of the boilers, that had caused them to fail; and yet it had been put down as the fault of steel generally, and had thus made people, without any real reason whatever, afraid of using steel.

His method of practically dealing with steel plates for boilers was as follows. He first punched all the holes by a template machine, using a large bolster: he then raised the plates just to a blood-red heat, and put them on one side to cool; and then did all the other work cold. When the plates were cold, they were bent into the proper circle, sponged with sal ammoniac, and put together. After the boilers were made, the whole of the scale was taken off inside with sal ammoniac and water; and as soon as they were dry they were given a coating of glycerine, if the boiler was likely not to be used at once, in order that corrosion might not go on any further. The small ends of the two punched holes were put together; and he liked to have a very deep head for the rivets, so that they should not give way. Rivet-heads were sometimes made so flat that they actually curled up round the edge, and so caused leakage. In the longitudinal joints he put the rivets in double shear by using a thin cover-plate outside and inside. In that case, and that only, he punched the hole about $\frac{1}{8}$ in. smaller than the finished size, and then put a rimer through the three thicknesses together, and they came as true as possible. On this method he was now making boilers at the rate of four every week—locomotive boilers working at 140 lbs. pressure; and they gave no trouble whatever.

Mr. W. Boyd thought it was a little unfortunate that the discussion should have already begun to wander away from the very interesting line that had been indicated by Professor Kennedy's paper. It appeared to him that, curiously enough, the most interesting points which had been developed in the investigation were not those which the Committee had immediately before them when they set about their experiments. When they began, their object was to lay before the Institution, on some conclusive, and as far as possible authoritative, basis, the best practical form of riveted joint. But, as the results of Mr. Tweddell's Table and Professor Kennedy's experiments showed, the joints in use in the best boiler-making practice coincided fairly with the joint which was found theoretically to be most satisfactory. But there were two points more particularly

brought out by Professor Kennedy's paper, which to him certainly were entirely novel. The first, and the most important of those points, was the very early period at which the material that had been tested showed signs of breaking down or giving way. That matter seemed to him to be one that had never been sufficiently considered; but the acceptation or rejection of Professor Kennedy's conclusions would have a most important effect upon the construction of all boilers, of all girders, and of all structures whose strength depended upon the vitality of steel such as that on which the experiments had been made. The material appeared to lose its full life, so to speak, at so much earlier a stage than they had been accustomed to imagine, that, unless some corrective could be applied, it appeared to him desirable at any rate that the fact should be thoroughly recognised in the designing of boilers and similar structures. This appeared to him to be the point brought out by Professor Kennedy's paper, which more than any other deserved attention, discussion, and deliberation on the part of the members.

Professor Kennedy had also propounded a most interesting theory as to the increased strength of the material after it had been punched or drilled. That was another point which might very well be discussed by the members present; and it appeared to him that the suggested explanation accounted well for what had always been an obscure problem.

The President said that, as to permanent set, he might refer the members to remarks he had made at a meeting held some time since (Proceedings 1878, p. 256), when he had mentioned that in experiments made upon iron tie-rods it had been found in every case that the set took place much earlier than had been generally supposed, or at about 8 tons per sq. in.

Mr. T. W. Traill thought that the valuable paper by Professor Kennedy, which had been read, deserved very full discussion and most careful attention; and he regretted that, owing to the short time he had been in possession of it, the few remarks he should make would not, he feared, be such as the paper merited. In

the first place he observed that Professor Kennedy said, p. 207, that within certain limits no difference was made by alterations in the width of the specimens tested. That, no doubt, was the result of Professor Kennedy's own observations; but it certainly was not in accordance with other experiments. He thought it very desirable that there should be a uniform width and length fixed for all test pieces, so that fair and reliable comparisons might be made. He entirely agreed with Professor Kennedy that the length should always be stated for which the extension was given; because if that were not known the results would be useless, in fact they might even be misleading and mischievous. Ten inches was a very convenient length for many reasons—if for no other, because it saved trouble in calculations—and he thought it should be always adhered to.

With reference to the elastic limit, he certainly thought that the point where uniform extension ended, as given in column II., Table III., was more satisfactory than the point at which the metal broke down: while if it was a very hard material the two would be coincident. He thought however that engineers need not alarm themselves on account of the permanent set that took place in mild steel, as it had been found that at the same proportion of the ultimate stress it was not greater than with good iron; and the tensile strength of mild steel was well known to be greatly above that of iron.

Professor Kennedy had made some interesting experiments with regard to the shearing strength of single rivets; but however scientific, and however valuable or interesting, they might be, the results were not the same as those that had been obtained in practice: as his own experiments on riveted joints had in fact shown. The results obtained with the shearing apparatus were much higher than those given in actual joints: and he thought it was worthy of notice that the shearing strength of rivets in practice was much less than was commonly supposed: their shearing strength was usually supposed to correspond to a much higher percentage of the tensile strength than was really the case.

It was stated on p. 216 that the mean diameter of the rivet holes had been taken in calculating the amount of metal removed, instead

of taking the smaller diameter of the hole. He thought that was hardly a desirable practice, and that a wrong impression might be formed from it. It was not only the strength of the net section that was wanted; it was the strength of the gross section of the joint, and the strength per inch run. Perhaps Professor Kennedy would allow him to suggest that when reprinting the paper it would be a great boon if he would add other columns to his Tables, giving the tensile strength per sq. in. of the individual plates which formed each joint, and the actual strength of the joint as compared with the calculated strength. These he thought would be found very useful to readers, in place of their having to make such calculations themselves. He hoped Professor Kennedy would continue these experiments for the Institution, going on with double lap-joints and double butt-joints after he had finished with single lap-joints.

Mr. R. C. Longridge said the first thing that occurred to him in reading Professor Kennedy's paper was the very high proportional strength of the joint No. 657-2, namely 63·7 per cent. (Table XXIII.). Speaking from memory, he believed that was the strongest single-riveted lap-joint which had been tested, either in iron or in steel. He was not altogether surprised at that result, because he believed it was greatly due to the large size of the rivets. He was already aware that by using larger rivets, even when the net sectional area of the plate was reduced, a stronger joint might be obtained. Another point, which had already been alluded to, was the relation between the proportions laid down in the paper and those met with in practice. Mr. Boyd had spoken of the results as rather confirming practice, but he hardly agreed with that view. Taking the formula given in p. 229, it would be found that for $\frac{1}{2}$ in. plates the holes would be $1\frac{1}{8}$ in. diameter, and $2\frac{17}{32}$ in. pitch. In practice he was not aware that they had anything like that. In Mr. Tweddell's statement, the nearest he could find for $\frac{1}{2}$ in. plates was, diameter of rivet $\frac{15}{16}$ in., pitch $2\frac{5}{16}$ in. Before seeing Mr. Tweddell's Table, he had intended to say that he did not think in ordinary boiler-making practice they met with a larger diameter for $\frac{1}{2}$ in. single-riveted joints than $\frac{7}{8}$ in., nor a wider pitch than about 3 in.; while according to Mr. Tweddell's Table,

p. 294, with $\frac{1}{2}$ in. plates and $\frac{15}{16}$ in. diameter rivets, the widest pitch was only $2\frac{5}{16}$ in. He did not think that he had ever himself seen a larger diameter than $\frac{7}{8}$ in. for $\frac{1}{2}$ in. plates.

The President pointed out that Mr. Tweddell's Table referred entirely to iron, whereas Professor Kennedy's experiments were all in steel.

Mr. Longridge said that certainly made a considerable difference. There was another point which had struck him as really the most remarkable part of the paper, namely what Professor Kennedy called the increase of strength due to the perforation of the plates. He happened to be acquainted with the particulars of a long series of experiments made with specimens of solid plates, of perforated plates, and of riveted joints; and in every single instance—whether the plates were annealed or unannealed, whether the holes were drilled or punched, whatever was the arrangement of the holes as to pitch, and whether the joints were single or double riveted—instead of there being an increase of strength due to perforation, there was an absolute loss. Those experiments however were with iron plates; and the results were corroborated by a series of experiments made by Mr. Kirkaldy on iron plates made at Krupp's works and at various Yorkshire works. In most of them there was an absolute decrease, instead of an increase, of strength due to perforation ; but in a few of them, in which the holes were drilled, he believed there was an increase, though only a slight one, nothing like so much as stated in the paper. Mr. Kirkaldy, in his remarks on the experiments, observed, and he himself believed correctly, that this was due not so much to any different effect of punching and drilling, as to a difference in the quality of the material used. Therefore he had no doubt that the fact of the plates which Professor Kennedy had experimented upon being of steel was sufficient to account for what at first appeared to be very remarkable.

He would venture rather to question the correctness of an expression used in the paper, p. 216, "natural tenacity," in connection with the testing of an unperforated plate. Afterwards it was

stated, p. 217, that "The inevitable consequence is that, before the material breaks, the stress on it is not uniform (as it is commonly assumed to be), but is much greater at the centre than at the sides;" and a little further on it was pointed out that, consequently upon the perforation of the plate, there was a more uniform stress on the section torn. Would it not be more correct to speak of the strength in the latter case as the natural tenacity of the plate? That was a point which Mr. Kirkaldy had referred to in his "Experiments on the strength of Wrought Iron and Steel," where he laid considerable stress on the reduction in sectional area after fracture.

The PRESIDENT observed that Mr. Kirkaldy generally gave in his Tables the reduced area of section at the point of fracture; and in some quarters there had been a practice of gauging the degree of ductility by that reduction of area; but that was rather a vexed question. Many persons considered that when the bar was drawn out small at the last moment, and a "waist" made to it, the strength was already gone, and that this therefore was not a good criterion.

Mr. LONGRIDGE thought at any rate the perforation of the plate seemed to equalise the intensity of the strain on the different parts; and therefore it appeared to him that it might be more correct to speak of the "natural tenacity" of the plate in that case than in the case where Professor Kennedy spoke of it, namely in the testing of an unperforated plate.

Mr. W. SCHÖNHEYDER considered the method adopted by Professor Kennedy in testing rivets for shearing was very ingenious, but it appeared to him to be open to a certain amount of doubt as to the results obtained; because, in shearing a rivet, as soon as a considerable stress was applied by the shearing dies BB, Fig. 3, Plate 30, the rivet would be distorted, would elongate to a small extent, and the dies would be forced asunder. That must cause a certain amount of friction in the chamber C, which would make the shearing resistance appear greater than it ought to be. Professor Kennedy would no doubt say whether he had found any considerable

friction to exist in testing the shearing of a rivet in that manner. It would be an improvement simply to hold the dies together by a bolt, instead of putting them into a chamber: in other words, to screw the ends of the rivet rod, and apply nuts to prevent the dies from separating. There would not then be the friction in the chamber, and a better effect would be produced.

Mr. W. S. Hall said, with regard to the coincidence of Professor Kennedy's figures and those of ordinary practice, it would perhaps be correct to say that they were tolerably coincident as to pitch, but not as to diameter. Taking the diameter as $2 \cdot 25 \times$ the thickness of the plate, and multiplying that again by $2 \cdot 25$ for the pitch, they would get something near the average proportion of pitch used in practice for single-riveted joints; but there would be a much larger diameter of rivet than was usually employed. He also thought that, when the experiments were carried on to double-riveted joints, it would be found that there was a much wider discrepancy between the figures for the strongest possible joint and those of actual practice. His experience of double-riveted joints was that as a rule too many rivets were put in them.

With reference to another point, it was absolutely necessary in practice to allow for the weakening of the joint by corrosion, as suggested in Baron Clauzel's paper, p. 201. Out of upwards of 200 cases of repairs to boilers, which he had personally superintended and examined, in all but one (which was in every way exceptional) he had found that the joint had failed through tearing or ripping of the plate, generally along the seam, but sometimes from the rivet hole to the edge. He therefore thought it was necessary to give an excess of strength to the plate, rather than to the rivet. Moreover it was easy to replace a rivet, if the rivet-head dropped off or anything of that sort happened; but it was not so easy to replace a plate when it was cracked through one or two holes.

Mr. Jeremiah Head wished to add his individual testimony to the great value of the two papers, although, on account of their length and the large number of calculations in them, it was only possible to catch

as it were a few points for discussion. The President had referred to a previous discussion when he had mentioned the point at which iron began to give way as being about 8 tons per sq. in., just about the same as in the case of Professor Kennedy's experiments. He believed the President had added that it was iron of a very soft character.

The President said it was not particularly so.

Mr. Head said the President would at least admit that the harder qualities of iron would stand higher strains before set began. The experience he had himself had was mainly with North-country iron, which was of a harder character; and that would certainly stand 11 or 12 tons per sq. in. without beginning to give way, and in many cases much more. But no doubt it was undesirable that iron should be so hard as not to begin to give way at something like 10 or 11 tons. In the case of mild steel great efforts had been made to make it soft, in order that the range, from its beginning to give way up to its final giving way, should be as long as possible. But perhaps that also might be overdone, because engineers did not want their structures, whether of iron or steel, to begin to give way at too early a period; but to be able to rely upon their remaining stiff and strong up to a certain known point.

With regard to riveted joints, it should not be forgotten that the papers were dealing with joints which had been tested as straight lines in a testing machine: whereas in a large number of constructions, as in the case of ship-building and boiler-making, the plates were curved. Now it had been truly said that, make the best joint they possibly could, still a solid plate was stronger than any joint; it therefore behoved them to take the greatest possible care to make their joints as strong as possible, and to see that every part of them was sound. In a previous discussion (Proceedings 1878, p. 582) he had called attention to the effect of punching rows of holes along the edge of a plate, and afterwards bending the plate cold. Now he was not quite sure whether in the case of very mild steel that mattered much or not; but he was quite certain that it did matter in the case of iron, especially if the bending were across the grain, and if, instead

of single-riveted joints, double riveting and especially triple riveting were used. If there were three rows of holes, as in the case of the boiler that had been referred to in the *Livadia*, the third row gave a great additional leverage for the rolls to act with; and certainly the plate would prefer to bend sharp at that row, rather than to bend equally throughout the part between the rolls. He had frequently seen in boiler-makers' works about the country, making small upright boilers where the grain of the plate ran vertically, that, if they were double-riveted and bent cold after punching, there was a sharp bend to be observed in both plates along the inside row of rivets, which was certainly very bad. In such a case, where a boiler-maker supposed he was getting extra strength by a double row of rivets, he was really making that part a very weak place in the boiler. But that was not the whole question. The effect of bending after punching was suddenly to increase the curvature at each line of rivets; and when the plate came to be brought round into a circle for a small boiler, it was evident that the two ends would come into the position shown (on an exaggerated scale of course) in Fig. 19, Plate 32. Then, since this joint had to be riveted together, the edges had to be knocked back by some means or other, and very likely in a country shop that would be done rather roughly; and that gave a still worse chance to those two points. He thought that engineers ought not to forget that weak point, not only in boilers, but also in ships. In the thick plates, $\frac{3}{4}$ in. or $\frac{7}{8}$ in. thick, which were about the bilge strake, all the holes were usually punched before any bending was done; then the plates were put through the bending rolls, and often they nearly broke through in that place. Of course the argument of the ship-builder was that if the plates would not stand that bending they were bad. He did not know that that was necessarily correct; but in any case he believed that plates were often thus injured, without any actual crack being seen. They apparently stood the test, and they were put into the ship; but they were weak at that point, and that was the point where they would finally give way.

Mr. W. John wished to know if Professor Kennedy could give any curve for iron, showing the extensions with different stresses, similar

to the one he had given in Fig. 1, Plate 30, for steel. He thought it would be found to be somewhat analogous. Some time ago, in trying to verify, for some calculations he was making, the modulus of elasticity, and analysing some of the results of tests, where the extension was given for different stresses, he found that the smaller extensions gave quite a different modulus of elasticity from what he got higher up the scale. For instance, taking the stretch at 5 tons per sq. in., he found a modulus of elasticity different from what he got by taking the corresponding stretch at 3 or 7 or 10 tons; and to such an extent was this difference impressed on his mind that he could not help thinking the modulus of elasticity, in dealing with structures, might have to be considered not as a constant, but as some function of the stress applied. The experiments conducted under the Research Committee by Professor Kennedy had been, as he understood, entirely with steel; but perhaps Professor Kennedy, in the ordinary course of his investigations, might have experimented similarly upon iron; and he was sure it would be very valuable both to that meeting and to the whole profession if they could get from him information on the point he had mentioned.

Another point to which he should like to refer was the effect of punching steel plates. Professor Kennedy's tests were all on $\frac{1}{4}$ in. or $\frac{3}{8}$ in. plates. He had himself both seen and made many experiments in this direction, and had found this very remarkable fact: that while punching had very little effect upon thin plates, it caused a great loss of strength in thick plates; in fact he had observed a loss of over 30 per cent. in experiments most carefully prepared, some with small and some with large specimens, and with widths of 7 or 8 in. of plate, having a couple of holes punched in them. Hence he thought that the conclusions drawn by Professor Kennedy as to the small injury done to steel by punching might be somewhat too favourable; and that if he continued these experiments with thicker plates, he would find it almost impossible to get results showing so little loss due to punching as was stated in his paper. The explanation given by Professor Kennedy of the results he had obtained was, he thought, very reasonable and very correct.

He was not sure whether the experiments described in the paper had gone sufficiently far to justify a general deduction that there was not much difference between testing a narrow strip and a wide plate. His own experiments rather tended to show that wide strips, especially with thin plates, were not so reliable as narrower ones. He thought they should be cautious in concluding that strips fairly represented plates under strain for all cases, so that a broad plate would break at the centre, and when the two parts were put together the edges would meet but not the centre, as stated in the paper, p. 217. And there was another peculiarity to be considered, which everybody must have noticed who had had experience in testing: namely that at the centre of the fracture the reduction in area was chiefly in thickness, the plate being drawn down thinner; whereas towards the edges, where the plate was free to contract in the other direction also, the contraction generally took place from the edges inwards, and the plate became narrower instead of thinner. Thus the contraction going on in a strip was almost entirely different towards the edges and towards the centre; and it would thus be seen there was room for much difference in behaviour between a narrow strip and a broad plate.

Mr. Druitt Halpin said he had lately seen some experiments made in testing steel bars, which might prove interesting to the meeting. The bars were about 1 in. in diameter by 10 in. long. The machine in which they were tested was made to record a perfect diagram of the stress acting, as well as of the amount the test-piece had elongated, at every moment during which the experiment was being carried out. The load was applied by means of hydraulic pressure generated in a differential accumulator, the original pressure for working the machine being derived from the water pressure in the town mains. Owing to the use of this arrangement, it was possible to make a test either in one or two seconds, or as slowly as might be desired; and it was interesting to note the fact that no difference could be detected in the diagrams obtained, whether the test was performed with the greatest possible rapidity, or in a more gradual manner. The counterbalance used for measuring the load applied was fixed on a bell-crank differential lever, so that it was

evidently perfectly self-adjusting—a matter of the greatest possible consequence, as it was in his opinion quite impossible to determine correctly either the limit of elasticity or the actual breaking load in any kind of machine of the ordinary construction, in which the weight on the lever had to be tentatively moved backwards and forwards by hand, to enable the lever to "float," and to put the load and resistance temporarily in equilibrium. By the use of this machine a very interesting fact was ascertained, which to himself at least was new: namely that the actual stress on the test-piece, at the moment when rupture took place, was always considerably below even the limit of elasticity. When this limit was passed, the curve of resistance on the diagram rose irregularly to a maximum; then dropped in the same way to a point lower than that corresponding to the elastic limit; and then fell vertically, indicating actual rupture. The explanation of the fact that rupture took place at a load much less than the maximum load which had been applied must be, he thought, that, after the limit of elasticity had been passed, the fibres of the material where it was fibrous, or the molecules in the case of steel, were so distressed, that they were unable any longer to offer sufficient resistance to the counterbalance, as to prevent it from travelling downwards at a greater speed than that at which it could be balanced by the hydraulic load transmitted through the test-piece.

Mr. Lavington E. Fletcher had but little to add to the very elaborate papers that had been read; but would offer a contribution on a point of some interest, bearing on the subject indirectly rather than directly.

Some time ago the Manchester Steam Users' Association had a boiler constructed for the purpose of subjecting it to a series of experimental hydraulic bursting tests. They made nine such tests, repairing each rent as it occurred, and then bursting the boiler again. In repairing the boiler for the last test the greater part of the outer shell was replated. These experimental bursting tests gave some useful practical results, which it might be of interest to refer to on the present occasion.

The boiler was 21 ft. long, and had a diameter in the shell of 7 ft., and in the furnace tubes of 2 ft. 9 in.; while both the shell and the furnace tubes were composed of seven rings of plating about 3 ft. wide. The plates were of iron, of Snedshill Best Best brand, and measured $\frac{7}{16}$ in. thick in the cylindrical portion of the shell, $\frac{3}{8}$ in. in the tubes, and $\frac{1}{2}$ in. in the flat ends. The longitudinal joints in the shell were double-riveted throughout in the first instance; but subsequently one plate with single-riveted joints was introduced, to afford the means of comparison. All the transverse joints were single-riveted, while the holes in the shell were punched, both in the single and in the double-riveted seams.

Under the hydraulic test the boiler burst at the double-riveted longitudinal seams, at a pressure of 300 lbs. per sq. in. when hand-riveted, and 310 lbs. when machine-riveted; while at the single-riveted seam it burst at a pressure of 275 lbs. per sq. in., this seam being machine-riveted.

After the hydraulic burstings were completed, double-riveted and single-riveted sample strip joints, corresponding as nearly as might be with those in the boiler, and made of plates cut therefrom, were sent to Mr. Kirkaldy to be tested in the ordinary way, in order to afford the means of comparing the results obtained by pulling the joints asunder in a testing machine with those obtained by bursting them in an actual boiler by hydraulic pressure. Also some plain strips cut from the boiler were tested, to show the tenacity of the plates.

The machine tests gave the following results. Sixteen test strips each 2 in. wide tore asunder, when pulled in the direction of the fibre, at a mean load of 20·6 tons per sq. in. of original sectional area, and 23·79 tons per sq. in. of fractured area. When pulled across the fibre they tore asunder under a mean load of 19·41 tons per sq. in. of original area, and 21·64 tons per sq. in. of fractured area. The mean extension on a length of 10 in. in the direction of the fibre was 7·4 per cent., and across the fibre 5·9 per cent. Two double-riveted sample strip joints strained in the direction of the fibre, and measuring $12\frac{1}{2}$ in. in width, with the rivets placed zigzag, were found to have a strength of 53·84 per cent. of the solid plate; while two single-riveted sample strip joints, also strained in the direction

of the fibre, and measuring 12 in. in width, were found to have a strength of 41·02 per cent. of the solid plate.

It was interesting to compare the results of the hydraulic burstings of the actual boiler with the machine tests. On calculation it was found that the metal between the rivets in the boiler bore as nearly as might be 20 tons per sq. in. at the moment of bursting; while the test strips, as already stated, broke at 20·6 tons per sq. in., calculated on the original area. The strength of the double-riveted seams in the actual boiler was 64·72 per cent. of the solid plate, and of the single-riveted seam 57·11 per cent.; while the strength of the double-riveted sample strip joints in the testing machine was 53·84 per cent. of the solid plate, and of the single-riveted joint 41·02 per cent., the joints being machine-riveted in each case. Thus the double-riveted joint attained a higher breaking strain by 20 per cent., and the single-riveted joint by 40 per cent., when burst in the boiler by hydraulic pressure, than when pulled asunder in a testing machine. Possibly however some allowance should be made for the fact that only one plate single-riveted was introduced at the longitudinal seams, all the others in the cylindrical portion of the shell being double-riveted.

There had lately been a discussion as to the correctness of Sir William Fairbairn's estimate of 56 per cent. for the strength of a single-riveted lap joint, as compared with the solid plate; but the results of these hydraulic boiler burstings appeared to agree with that estimate of Sir William Fairbairn's very closely.

The fact that these hydraulic tests showed that the strength of the seams of rivets in the actual boiler very much exceeded that of the sample strip joints in the testing machine, seemed to him to be important, and to be worthy of further investigation. It was generally assumed that the results obtained by tearing riveted joints asunder in a testing machine represented the strength of the joints in a boiler. These experimental boiler burstings however had shown that such was not the case, but that a boiler was stronger than it had generally been assumed to be, from the results of experiments on riveted joints conducted with a testing machine. If lap joints which had been strained in a testing machine were examined, it would be seen that

the plates were curled up at the ends. The plates were subjected to a cross-breaking action. They were not fairly torn, but were broken in detail little by little, commencing at the skin of the convex or outer side of the bend. In the boiler, the double thickness of metal formed by the overlap of the transverse seams acted as so many stiffening rings, and prevented the distortion of the seams, somewhat as encircling hoops stiffened a flue tube and prevented collapse. In this way the joints were kept up to their work, until they were fairly pulled asunder. One or two engineers to whom he had mentioned these facts rather doubted the correctness of the view, and thought that as these hydraulic bursting tests had been applied only to a single boiler they required repetition to afford them confirmation. Under these circumstances, as the Institution of Mechanical Engineers had begun to investigate the strength of riveted joints, it appeared to him desirable that they should follow it up by making some further hydraulic bursting tests of actual boilers; and he would recommend this subject to the consideration of the Council.

It had been questioned by a previous speaker whether punching a hole in a plate really did strengthen it. Some plates 12 in. wide, tested by Mr. Kirkaldy for the Manchester Steam Users' Association, were perforated with a row of punched holes running across them, the bolster being about $\frac{1}{16}$ in. larger in diameter than the punch. These were certainly found to attain a higher breaking strain than the plain 2-in. test strips: of course he did not mean in the gross, but *pro ratâ*.

With regard to the pitch of rivets, he thought boiler-makers were often wrong in putting them so close together; they wanted to make a tight boiler under test, and were afraid of its leaking. Some time ago a boiler tested with hydraulic pressure by the Manchester Steam Users' Association, having a diameter of 6 ft. 6 in., and made of plates only $\frac{3}{8}$ in. in thickness, was found to be quite tight at 120 lbs. per sq. in., though the rivets were pitched as much as 3 in. apart. Other boilers had been quite tight with rivets pitched as much as 4 in. apart.*

* Four marine boilers, 8 ft. 6 in. in diameter and made of plates 9-16ths in. in thickness, were found to stand a hydraulic test of 160 lbs. per sq. in.

Referring to the importance of making boilers truly circular, he stated that he had lately had brought under his notice three locomotive boiler explosions, in which the primary rent had occurred just at the edge of the inner overlap, in one of the longitudinal seams of rivets in the barrel of the boiler, although the plates were of Low Moor iron and the boilers by first-class makers. Engineers were familiar with the ordinary groove or furrow, from which several locomotive boiler explosions had occurred. In this case however there was no furrow, but a fine hair crack lurking under the edge of the overlap. The locomotive superintendent, to get at the bottom of the matter, cut up the boiler of a sister engine that had not failed; and on taking the plates out and bending them back at the overlap, he found they were cracked almost through to the skin in some places, although the crack was so fine that it might easily have escaped detection. In the barrels of locomotives he recommended that the longitudinal joints should be made with double butt-strips, one inside and the other outside, so that the boiler might be truly cylindrical, and thus changes of shape under alternations of pressure avoided, and grooving prevented.

Mr. W. W. Beaumont, referring to the diagram of extensions, Fig. 1, Plate 30, said that two or three speakers seemed to be afraid lest the early appearance of set indicated that it would be necessary to take some point much lower than the ordinary limit of elasticity, as the basis to go upon in fixing the strength of any particular structure. But on observing the exceeding minuteness of the actual extensions, instead of merely glancing at the magnified diagram, the scale of which conveyed at first sight an exaggerated idea, it would be

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satisfactorily, nothing beyond a few unimportant tear drops occurring here and there, though the pitch of the rivets was as much as 4·14 in. In this case the longitudinal seams were double-riveted, and made with double butt-strips 7-16ths in. thick, one placed inside the boiler and the other outside, so as to put the rivets in double shear. The diameter of the rivets was 15-16ths in., the pitch longitudinally 4·14 in., as already stated, and diagonally $2\frac{3}{4}$ in., so that one row was placed $1\frac{5}{16}$ in. behind the other; the holes being drilled, and the riveting done by machine.

seen that really the set was so very small up to the limit of elasticity that no fear need arise as to their being able to use the old limit of elasticity. There was no doubt a certain amount of set previous to arriving at the strain which produced destructive elongation; but it was very small indeed.

Mr. W. Schönheyder asked if Mr. Fletcher could state what was the least distance apart from centre to centre of the two rows of rivets in the joint he had spoken of, which was quite tight with a 3 in. pitch. Of course this depended upon what was the actual distance between rivets necessary to make a tight joint: when measured diagonally it might prove to be as little as 2 in., and that would account for the tightness.

Mr. Fletcher replied that the two rows of rivets were $1\frac{3}{8}$ in. apart, and while the longitudinal pitch was 3 in. the diagonal pitch was $1\frac{7}{8}$ in. He thought wider pitches and larger rivets than those generally adopted would make a stronger joint. But it was very difficult to get boiler makers to pitch their rivets further apart in ordinary land practice than $2\frac{1}{2}$ in. He did not doubt they might exceed this pitch, but they did not like to risk it.

Mr. Jeremiah Head begged permission to ask Mr. Fletcher a question. He understood him to say that, according to his experience, the part between the rivet-holes was actually strengthened by the punching, and that it was when the bolster was relatively large that the increase of strength occurred. But, referring to the sketch, Plate 32, Fig. 17, suppose P to be the punch, L the part of a plate being punched through, R the burr that was driven out, and DD the bolster; then if the hole in the bolster was a pretty good fit with the punch, the burr would generally be found to come through perfectly sound, provided the plate was of anything like reasonable quality. But if the hole in the bolster was much larger than the punch, as in Fig. 18, then, whatever the quality of the plate, the burr would be bulged out as shown, and cracked on the lower side, leaving of course a conical hole in the plate. Now if the hole in the

bolster was a good fit, and the punch went clean through, one would expect that the metal on the surface would be compressed in the first instance, and forced outwards before it began to give way; and therefore that there would be some increase of density round the hole. But if it was a wide hole, then to some extent the metal of the burr was torn out sideways all round; and one would expect that if anything the metal round the hole would be rather disturbed and weakened than the reverse. Perhaps Mr. Fletcher would explain whether, in his opinion, it was really the large hole in the bolster that produced the good effect on the strength of the iron left between the holes.

Mr. Fletcher said he thought the cause of that effect had been treated of in the paper. He might state however that, as a matter of fact, in the tests conducted by Mr. Kirkaldy for the Manchester Steam Users' Association, the plates perforated with a row of punched holes did stand more *pro ratâ* than those not perforated. That effect he believed to be due to the fact that the perforated plate tearing through the holes did not stretch as much as the plain plate, and the contraction of area at the line of fracture was thus less in the perforated plate than in the plain one.*

The President pointed out that experiments had been tried with steel plates (p. 216), both with large bolsters and small, and there was very little apparent difference.

Mr. Charles E. Cowper wished to know whether there was any difference between the result obtained with a plate having straight sides but perforated in the middle, as shown in Fig. 7, Plate 31, and one with hollows in the sides (produced by cutting through the centres of two rivet holes) and also perforated in the middle, as

* The following are the particulars of the tests previously referred to of two punched plates, which were torn asunder in a testing machine along the lines of fracture shown in Figs. 8 and 9, Plate 31. The holes were filled with dummy rivets, so that they might be as nearly as possible under the same condition as when in the joint of a boiler.

shown in Fig. 6. It appeared to him that the hollowing out of the plate at the sides might be very likely to give a different result, as to the proportion of strength. Perhaps Mr. Fletcher would kindly state whether in his opinion the difference between the two arrangements was of any importance, and if so which was the fairer way of testing a plate, in order to represent the conditions in the actual boiler.

For sketch of test strips, see Figs. 8 and 9, Plate 31.	Fig. 8.		Fig. 9.	
Data.	Iron.		Iron.	
Quality of plates	Best Best Snedshill		Best Best Snedshill	
Size of plate	12 in. × 0·45 in.		12 in. × 0·46 in.	
Sectional area of Plate, gross, *i.e.* including rivet holes . . .	5·40 sq. ins.		5·52 sq. ins.	
Sectional area of Plate, net, *i.e.* excluding rivet holes . . .	3·32 sq. ins.		3·39 sq. ins.	
Ratio of net to gross sectional area	62 per cent.		62 per cent.	
Rivets, diameter and pitch . .	0·77 in. and 2 in.		0·77 in. and 2 in.	
Rivet holes, punched or drilled .	Punched		Punched	
Plates, direction of grain . .	Lengthways		Lengthways	
Results.	Lbs.	Tons.	Lbs.	Tons.
Total ultimate stress . . .	169,490 =	75·6	182,410 =	81·4
Ultimate stress per sq. in. of sectional area of plate, gross . . .	31,385 =	14·0	33,049 =	14·7
Ultimate stress per sq. in. of sectional area of plate, net . . .	51,051 =	22·8	53,808 =	24·0
	Mean 23·4 *tons*			
Ultimate stress per sq. in. of solid plates, as deduced from test strips 2 in. wide	43,865 =	19·6	45,154 =	20·2
	Mean 19·9 *tons*			
Ratio of strength of gross sectional area to strength of 2 in. test strips	71 per cent.		73 per cent.	

From the above it will be seen that, while the plain test strips attained a mean breaking strain of only 19·9 tons per sq. in., calculated on their original sectional area, the punched plates attained a mean breaking strain of 23·4 tons, being 3·5 tons in excess, equal to 17·6 per cent. But if the breaking strain of the plain test strips is taken on their fractured area instead of on their original area, the result will be different: their strength will then be 22·1 tons instead of

Mr. Fletcher said he should expect that Fig. 6, Plate 31, which showed a specimen with the sides hollowed out so as to narrow the plate down to a waist at the middle, would give the better result. In a plain strip considerable elongation ensued, and thus considerable reduction of area at the point of fracture, especially if the plate were ductile. The same elongation however did not take place in a plate narrowed down to a waist; the fracture in such shapes ran, under ordinary circumstances, through the smallest section; and as the shape of the metal widened out on each side of the waist, its greater section, and consequent greater strength, supported the metal at the line of fracture, and thus reduced the contraction of area and the consequent loss of strength.

The President on referring to the paper (p. 218) stated that the specimen shown in Fig. 6, Plate 31, did yield a higher result than Fig. 7, as Mr. Fletcher had anticipated.

Mr. R. H. Willis said that, in conjunction with Professor Kennedy, he had made other experiments which bore a little on that point, though they were not immediately in connection with the riveting experiments. They were experiments on the tenacity of screwed bolts, which were, of course, of a form somewhat analogous to that in Fig. 6,

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19·9 tons, so that the excess would be reduced from 3·5 to 1·3 tons per sq. in.; while there is no doubt this difference would vary in a number of specimens.

The effect of the shape of a specimen upon its strength is treated of by Mr. Kirkaldy in paragraph 171 of his "Experiments on Wrought-Iron and Steel," where he says: "It will be observed that the grooved pieces invariably bore the highest comparative strains, and also that they invariably contracted least. . . . . By simply changing the shape of the specimens, so as to interpose an obstacle to their drawing out, a much higher breaking strain was obtained." Further on, in paragraph 197, conclusion 48, he states: "The breaking strain is materially affected by the shape of the specimen. Thus the amount borne was much less when the diameter was uniform for some inches of the length than when confined to a small portion—a peculiarity previously unascertained and not even suspected." Mr. Traill, engineer surveyor in chief to the Board of Trade, in his most elaborate report entitled "Experiments on Steel," also refers to this subject (see page 14).

Plate 31, since the section had its diameter reduced at intervals by the groove of the thread. The elongation being thus prevented, it was found, on breaking the bolts in the thread, that the tenacity in the case of iron and steel bolts was much greater per sq. in. of material fractured than in a test piece which could extend freely. This increased tenacity would appear to be simply due to the grooving, and the consequent prevention of flow of material.

Professor W. C. Unwin being unable to be present, the following observations received from him were then read by the Secretary, by permission of the meeting :—

"The first point of importance brought out in these experiments seems to be that, when the specimens are properly designed, and when the experiments are made with the requisite skill and care, the size of the specimens has very little influence on the results. If anyone will examine the older experiments on punching and drilling, or even the very careful experiments of M. Barba, he will find that this was not the case in those earlier experiments. When the results with different sized specimens are not uniform, it must be inferred that either the mode of preparing the specimens, or the mode of testing them, must have injured some of them. The specimens of punched and drilled plates used by the Committee differ in two ways from most if not all specimens previously tried :—(1) they are cut from a wide plate, punched or drilled previously; (2) they are so cut that the flow of the metal, after the elastic limit is passed, is similar to that in an indefinitely wide plate.

"The experiments show a considerable gain of strength in drilled plates, and a less gain (but still a distinct gain) in punched plates, when compared with ordinary test bars. This kind of gain of strength was first noted in the First Report of the Committee, *infra* p. 319, and was confirmed by Mr. Adamson's experiments (p. 313) made while that report was under discussion. A gain of strength of a similar kind had indeed been noted before in riveted joints, as for instance in Messrs. Greig and Eyth's experiments; but this gain of strength has always hitherto been attributed to the friction of the riveted joints.

"In the First Report, p. 319, some weight was laid on the gain of strength in short test bars, which is due to restricting the selection of a weak section by the testing load when the bar is shortened. Professor Kennedy, I think quite rightly, rejects this as an insufficient explanation of the gain of strength observed in drilled and punched plates. His own explanation however appears to me not only insufficient but incorrect. He observes that scribed lines on an ordinary test bar become concave to the fracture, because the flow of the material is greatest towards the edges and least at the centre of the specimen. He infers from this that at the moment of fracture the stress is not uniform on the section, but is greater at the centre than at the sides. In the drilled specimens the flow is more uniform; the scribed lines remain more nearly parallel to the section of fracture; and hence Professor Kennedy infers that the stress on the section of fracture is more uniform than in an ordinary test bar, and the mean breaking stress greater.

"I do not myself believe that the permanent set taken by the material indicates in any way the state of stress at the moment of fracture. Certainly there is no proof that where the flow is great the stress is small, and where the flow is small the stress is great. So far as I can judge, the stress is likely to be at least so uniform on the section of fracture of an ordinary test bar, in spite of the different flow of different parts, as to make Professor Kennedy's explanation seem even more inadequate than the previous one which he rejects.

"The explanation of the apparent increase of strength in drilled plates is probably extremely simple. The comparatively unstrained metal behind the rivet holes prevents the flow of the metal, which occurs in test specimens of ordinary length. The consequence of this is that in the drilled specimens the contraction of area is less than in ordinary test bars; and the contraction of area being less, there is a greater strength. I have found, in experimenting with india-rubber, that there is this diminished contraction of area in bars with holes in them; and I have no doubt Professor Kennedy will find it is also the case with the specimens tested for the Committee. At any rate the contraction of area of these specimens should be measured if possible.

"As to bearing pressure, I think it is clear that the old idea that a high bearing pressure caused a diminution of tenacity in the plates receives no confirmation in these experiments. Some of the experiments do seem to show that the bearing pressure was high enough to injure the rivets; but the evidence of the experiments on this point is very contradictory. It is of course possible that the bearing pressure may have been high enough to deform the rivets, diminishing their section and thus decreasing their strength. If so, the rivets were rather too soft. Still I incline to think that bearing pressure may be excluded from consideration in future, in designing riveted joints."

The President said he had only a few words to add in reference to Professor Kennedy's excellent paper. He quite agreed that the set in the plates at the very commencement was so small as really not to be at all alarming. He had many times riveted up girders and broken them, for the purpose of testing their ultimate strength, and whenever that had been done there had always been a slight noise before any breaking down had taken place or any rivet-head had flown; this was probably owing to the motion of the angle-irons upon the plates, or the rivets giving a little in the holes. He believed in every ductile material there was a certain amount of accommodation —a slight stretch or set—which took place long before the ultimate strength was arrived at. He did not think that was really a serious matter. It did commence, as Professor Kennedy had said, very early indeed; and it depended very much upon the accuracy or delicacy of the instrument employed, how soon the permanent set could be registered. He had before described (Proceedings 1878, p. 256) an "Extensometer" used by himself which would measure a ten-thousandth of the length of the instrument; and with it he had ascertained that the set in iron bars began very early.

He thought it very likely that some of the plates in boilers, which had given way at the seams where grooving was taking place, had been injured by bending in the manner spoken of by Mr. Fletcher. A mere hair-crack might commence the injury to the boiler at the seams, which of course, when riveted up, tended to bend under the

ordinary straining of the boiler. He thought such a crack might often have given rise, at all events, to the starting of the grooving and injury to the boilers.

With regard to Mr. Schönheyder's remarks as to friction in the shearing apparatus, Fig. 3, Plate 30, the length of the block B was $4\frac{1}{2}$ in., and it could not possibly be assumed that there was more than a quarter of an inch distance between the two centres of pressure in the two blocks, to give a leverage to throw them out of line: so that there was not more than an angle of 1 in 18 to cause any side pressure against the chamber; and he thought that the amount of friction would be very small. Another confirmation of the fact that there was not much jamming was that the blocks were easily knocked by a light hammer out of the chamber, after the strain was taken off. At that time the two pieces of the rivet were past each other, and were jammed, if ever they were jammed, to the full extent.

He thought the Institution ought to thank Professor Kennedy very heartily indeed for his paper. He had not only devoted a very large portion of his time to the experiments, but he had also gone down to Barrow and spent several days there, in order to satisfy the Committee by trying a number of experiments on large specimens, so that there should be no question at all as to the test-pieces being too small or too narrow. He had there used the machine which Mr. Smith of the Barrow Steel Company had kindly placed at the disposal of the Committee—a machine that would test up to 100 tons with facility. Professor Kennedy had previously given them the free and entirely gratuitous use of his proving machine at University College. This was an excellent machine, and had some beautiful arrangements about it that had not been referred to in the paper. He might mention one of them, namely, that for measuring the extensions. There was a little mirror on the machine, connected by a connecting-rod with the piece of metal to be tried, and turning on its axis as the extension increased. By means of a telescope fixed upon the machine the reflection of a scale placed upon the ceiling 15 ft. above could be seen in the mirror; and as the mirror tilted by the piece extending, new points on the scale came into the focus of the telescope. There was thus an imponderable

lever, a ray of light 15 ft. long, moving against the ceiling on a scale, so that very small extensions could be seen, down to a ten-thousandth part of an inch. He had himself used the machine on other occasions, but he was glad to have the opportunity of thanking Professor Kennedy for the use of it gratuitously on the present occasion, in the way which he had explained. He therefore begged to propose a very hearty vote of thanks to Professor Kennedy for his very kind exertions.

Professor Kennedy, being unavoidably prevented from being present at the close of the discussion, replied in writing as follows:—

"I must point out in the first place that the results of the experiments do not confirm the proportions given in Mr. Tweddell's most useful Table, as some speakers appear to have thought. The mean proportions for a $\frac{3}{8}$-in. plate and single-riveted lap-joint, given in that Table, *if used for steel plates*, correspond to a strength of only 43 per cent. *of the solid plate*, and the best proportions (column F) to only 51 per cent. Compared with 61 per cent., obtained in my experiments, it appears to me that there is here a great difference. It is hardly to be expected however that there should not be a difference, as the Table represents proportions for iron joints, and my work has been entirely with steel ones.

"The points which the experiments seem to me to have brought out most clearly are (1) that by the use of a ductile material the joint is helped very materially by the great excess of strength in the plate after perforation; and (2) that, while the *plate* is so much stronger than before, there is no corresponding increase in the shearing strength of the rivets, over the strength commonly taken as that of iron rivets. In consequence of these two facts, the proportions of a joint of maximum strength in a soft steel plate differ materially from those for an ordinary iron plate, in the direction of requiring a much larger proportional rivet area; and I venture to think that in bringing this matter out clearly, the experiments may enable engineers to adopt a much stronger form of joint than has often been

adopted; especially if it has anywhere been assumed that the proportions found best for iron joints should be continued for steel ones.

"It is worth while noticing that with steel plates the proportionate strength of single-riveted joints diminishes much faster, as the plates get thicker, than with iron plates, in consequence of the impossibility of getting so near the proportions of maximum strength by using large enough rivets. Hence any practicable *single-riveted* joint in a thick steel plate will be no stronger than in iron—a point which I have not seen anywhere noticed, but which has considerable practical importance. The limit will be found to lie at about $\frac{7}{8}$-in. or $\frac{15}{16}$-in. plate, beyond which thickness the strength of a single-riveted lap-joint will be much the same per inch breadth of plate (with any practicable pitch and diameter of rivet), whether the plate be steel or iron.

"In reference to a good many remarks which have been made about the very early commencement of *permanent set*, I may direct attention to the footnote on p. 209 of my paper. This feature is not peculiar to mild steel, but seems to belong rather to all very ductile materials. In considering its possible influence on practical design, the extremely small magnitude of the quantities dealt with (some values of which are given in the paper) must of course be borne in mind.* I do not myself think that the permanent set which occurs below the point at which the extensions cease to be uniform is generally of sufficient magnitude to be taken into account, in connection with questions relating to factors of safety. I may just add that there are some hard materials (*e.g.* cast iron and some tempered steel), where the extensions increase faster than the load from the very beginning, so that the diagram Fig. 1, Plate 30, has then no straight part in it at all; and in these cases it will frequently if not always be found that permanent set occurs *from the very commencement*, owing no doubt to the material having been in a condition of initial strain. A repetition of the test, with a piece of such material, gives for each load an extension less than that

* The right-hand curve in Fig. 1, Plate 30, shows the actual extensions, full size.

given for the same load in the first test, by an amount approximately equal to the amount of *permanent* set after that load in the first test. This is a matter which I have recently worked at a good deal, and which gives very interesting results. In many cases the curved line found in the first test becomes very closely a straight line in the second. It is important to notice that the calculation of the modulus of elasticity, in such material, cannot properly be made from the extensions observed on a first experiment. I am glad of Mr. Tweddell's suggestion of 'Limit of Fatigue,' which may turn out a very serviceable expression.

"The remarks made by Mr. Longridge and Mr. Head emphasise very strongly the difference between a very hard and non-elastic material, such as ordinary iron boiler plate, and a ductile material such as I have been dealing with in mild steel; and by inference emphasise also the necessity of considering separately the best proportions for joints in these different materials. Mr. Longridge's suggestion as to the proper use of the expression 'natural tenacity' appears justifiable in principle, and it would have been better had I used some other phrase; but there would obviously be practical inconvenience in actually using the expression 'natural tenacity' for a resistance occasionally 25 per cent. greater (as in Series VIII.) than that obtained in ordinary tests.

"In reference to Mr. Schönheyder's remarks about the shearing apparatus, there is undoubtedly *some* friction to be overcome, and this *is* included in the result, which is therefore somewhat in excess of the true shearing resistance. But as the total pressure required to shear the specimens was often nearly 20 tons, while the blocks could be knocked out of their bolster after fracture (although they were then quite overlapping each other and jammed firmly together) by a light hammer, I do not think that the friction can have sensibly affected the result. But of course, if I knew of any other equally satisfactory way of doing the shearing experiments, which would do away altogether with the friction and still hold the two blocks truly together, I should be very glad to employ it.*

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* Since writing this I have tried the method suggested by Mr. Schönheyder,

"In answer to Mr. John's question, I have always found that with ordinary materials (the only exceptions being such as I have just mentioned in speaking of permanent set) the extensions are, with wonderful exactness, proportional to the load up to such a point as the 14·78 tons per sq. in. in Fig. 1, Plate 30; and that therefore the modulus of elasticity *is* constant. I refer of course only to the case where the extensions are measured between two points upon the specimen itself, for I do not think that these small extensions can be accurately determined in any other way. I may add that, in speaking of the effect of *breadth* of specimen, I was careful to guard myself by stating the limits of breadth within which I had experimented, and within which I had found substantially identical results. In reference to another question of Mr. John's, the diagram Fig. 1, Plate 30, may be taken as almost identical with that to be obtained from measurements on a very ductile piece of bar *iron*, except that the permanent set might in that case commence sooner than 8 tons per sq. in. In hard iron the 'break-down' of the material would not be nearly so well marked, but it still remains sufficiently distinct to form what is usually given as the limit of elasticity of the iron. The only wrought iron which I have not found distinctly to 'break down' has been very inferior plate tested across the fibre, the actual breaking load of which was very little in excess of what its limit of elasticity ought to have been. I have not made many experiments on the first occurrence of permanent set in inferior iron; but so far as I have gone it seems to occur, in general, quite as soon as in good iron.

"In reference to Mr. Halpin's remarks, it appears to me that he does not quite know the working of the machines which he criticises. There is nothing 'tentative' about the determination of the limit of elasticity. The fact that the actual breaking load is often much less than the maximum load ought to be familiar to every one who has

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and find that it certainly gives lower results than the method I used. In spite however of tightly screwing up the nut, I found it impossible to prevent the blocks separating slightly, so that the shearing edges were sensibly not fairly together. Whether this is sufficient materially to affect the result, I cannot say without further experiment.

made tests; and indeed, after the stress laid upon it in Mr. Adamson's paper read before the Iron and Steel Institute in September 1878, it should be known to all engineers. In the rivet steel of Series III. the actual load at fracture was just about equal to the load at the limit of elasticity, in the cases in which I determined the former; but I have not myself found any cases so striking as those which Mr. Halpin mentions, where the final load was sensibly *below* the load at the limit of elasticity. In the case of these plates, the load under which fracture took place I determined to be (in some additional strips tested) about 85 per cent. of the maximum load, and therefore very much above the limit of elasticity.

"On the point raised by Professor Unwin I am, I must say, unable to agree with him. I do not see any means at present of finding what the actual area of a specimen is at the moment when it is standing its greatest load. In the perforated specimens fracture actually took place *at the greatest load*, in the unperforated specimens *at a much lower load* (as I have already mentioned); and therefore the final areas are not directly comparable. I have lately endeavoured to get exactly comparable cases by testing against each other a pair of pieces of Landore "S.S." steel, cut from the same plate and shaped respectively like Figs. 6 and 7, Plate 31, the holes being drilled. Both broke just at their maximum load, so that their results were strictly comparable. The first (Fig. 6) stood 34·73 tons per sq. in., and the second (Fig. 7) 32·31 tons per sq. in., each on its original area. The ratio between these two quantities is 1·07 to 1·00. The nature of the fractures was exactly as I have described in my paper: the one broken uniformly across, the other far the most extended at the sides of the hole, only the outer edges of the piece touching when the two halves were brought together. The former however is reduced 34·2 per cent. in area, and the latter only 29·8 per cent. The *actual* maximum stress was therefore in the one 52·76 tons per sq. in., and in the other 46·01 tons per sq. in.; and the ratio between these quantities, 1·15 to 1·00, is actually *greater* than the ratio of the nominal breaking loads. In this case then the excess of strength was accompanied by a *greater* and not by a *less* reduction of area; which I confess appears to me conclusive on the point,

unless there is something exceptional about the result of my experiments. Of course I quite admit that the portion of the bar which is being drawn out locally, where fracture afterwards takes place, is not in the same condition as a piece of ordinary iron within its elastic limit, and that no doubt the relations of stress to strain are very much modified in the former case. Whatever these relations may be however, I do not see how the same stress conditions can accompany fractures of so markedly different a type as those of which I have spoken, and which are illustrated in Figs. 4 to 7, Plate 31.

"In conclusion I should like to express my sense of the value of Mr. Fletcher's very practical remarks. I am also much obliged to Mr. Traill for the suggestions he has made. Some additions have been made to the Tables which will facilitate finding the tensile strength of each plate used in the riveted joints. The calculated strength of the joint would, I fear, be a quantity requiring so much explanation (as to the assumptions made in the calculation and so forth) that it would hardly be very useful. The Tables contain the strength of the joint per inch breadth of the plate, and the comparison of this with the strength of the solid plate."

APPENDIX I. ON RIVETED JOINTS.

TABLE SHOWING RULES OF PRACTICE USED BY VARIOUS MANUFACTURERS FOR RIVETED JOINTS ENTIRELY IN IRON.

Compiled by Mr. R. H. TWEDDELL.

N.B.—p denotes the strength of the *Plate* in the joint, per cent. of solid plate.
r " " *Rivets* " " "

[It is assumed that the tensile strength of the plate and the shearing strength of the rivet are equal, and no allowance is made for loss due to punching or drilling.]

With rivets up to 1 in. diameter it seems to be the universal practice to make the "margin," or distance from outside of rivet to edge of plate, equal to the diameter of rivet. With very large rivets, $1\frac{1}{16}$, $1\frac{1}{8}$, or $1\frac{1}{4}$ in. diameter, some makers allow rather less margin, namely 1, $1\frac{1}{16}$, $1\frac{1}{8}$ in.

Single-Riveted Lap-Joints.—*Dimensions all in Inches.*

Thickness of Plate.	Dimensions and Ratios.	Authority.							
		A	B	C	D	E	F	H	J
$\frac{5}{16}$	Diameter	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$		
	$\frac{\text{Diameter}}{\text{Thickness}}$	2·00	2·00	2·00	2·00	2·00	2·00		
	Pitch	$1\frac{5}{8}$	$1\frac{3}{4}$	$1\frac{5}{8}$	$1\frac{5}{8}$	$1\frac{5}{8}$	$1\frac{5}{8}$		
	$\frac{\text{Pitch}}{\text{Diameter}}$	2·60	2·80	2·60	2·60	2·60	2·60		
	Strength %	60 r	56 r	60 r	60 r	60 r	60 r		
		62 p	64 p	62 p	62 p	62 p	62 p		
$\frac{3}{8}$	Diameter	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{4}$		$\frac{3}{4}$	$\frac{3}{4}$	$\frac{5}{8}$	$\frac{11}{16}$
	$\frac{\text{Diameter}}{\text{Thickness}}$	1·66	2·00	2·00		2·00	2·00	1·66	1·83
	Pitch	$1\frac{3}{4}$	2	2		$1\frac{3}{4}$	$1\frac{7}{8}$	$1\frac{3}{4}$	$1\frac{3}{4}$
	$\frac{\text{Pitch}}{\text{Diameter}}$	2·80	2·66	2·66		2·33	2·50	2·80	2·55
	Strength %	47 r	59 r	59 r		57 p	60 p	47 r	57 r
		64 p	62 p	62 p		67 r	63 r	64 p	61 p

SINGLE-RIVETED LAP-JOINTS—*continued.*

Thickness of Plate.	Dimensions and Ratios.	Authority. A	B	C	D	E	F	G	H	I	J
$\frac{7}{16}$	Diameter	$\frac{11}{16}$	$\frac{7}{8}$	$\frac{7}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	$\frac{13}{16}$				$\frac{13}{16}$
	Diameter / Thickness	1·57	2·00	2·00	1·71	2·00	1·86				1·86
	Pitch	$1\frac{7}{8}$	$2\frac{1}{4}$	$2\frac{1}{8}$	$1\frac{7}{8}$	$1\frac{7}{8}$	2				2
	Pitch / Diameter	2·73	2·57	2·42	2·50	2·14	2·46				2·46
	Strength %	45 *r* 63 *p*	61 *r* 61 *p*	59 *p* 65 *r*	54 *r* 60 *p*	53 *p* 73 *r*	59 *r* 59 *p*				59 *r* 59 *p*
$\frac{1}{2}$	Diameter	$\frac{3}{4}$	$\frac{7}{8}$			$\frac{13}{16}$	$\frac{7}{8}$				$\frac{15}{16}$
	Diameter / Thickness	1·50	1·75			1·62	1·75				1·87
	Pitch	2	$2\frac{1}{4}$			2	$2\frac{1}{8}$				$2\frac{5}{16}$
	Pitch / Diameter	2·67	2·57			2·46	2·43				2·47
	Strength %	44 *r* 62 *p*	53 *r* 61 *p*			52 *r* 59 *p*	57 *r* 59 *p*				60 *r* 60 *p*
$\frac{9}{16}$	Diameter	$\frac{13}{16}$	$\frac{7}{8}$		$\frac{7}{8}$	$\frac{13}{16}$	$\frac{15}{16}$				1
	Diameter / Thickness	1·44	1·55		1·55	1·44	1·67				1·78
	Pitch	2	$2\frac{1}{4}$		$2\frac{1}{8}$	2	$2\frac{1}{4}$				$2\frac{9}{16}$
	Pitch / Diameter	2·46	2·57		2·43	2·46	2·40				2·56
	Strength %	46 *r* 59 *p*	48 *r* 61 *p*		50 *r* 59 *p*	46 *r* 59 *p*	55 *r* 58 *p*				54 *r* 61 *p*
$\frac{5}{8}$	Diameter	$\frac{7}{8}$	$\frac{7}{8}$				1		$\frac{3}{4}$	$\frac{7}{8}$	
	Diameter / Thickness	1·40	1·40				1·60		1·20	1·40	
	Pitch	$2\frac{1}{4}$	$2\frac{1}{4}$				$2\frac{3}{8}$		2	$2\frac{1}{4}$	
	Pitch / Diameter	2·57	2·57				2·37		2·67	2·57	
	Strength %	43 *r* 61 *p*	43 *r* 61 *p*				53 *r* 58 *p*		35 *r* 62 *p*	43 *r* 61 *p*	
$\frac{11}{16}$	Diameter	$\frac{15}{16}$	$\frac{15}{16}$				$1\frac{1}{16}$		$1\frac{1}{8}$		
	Diameter / Thickness	1·36	1·36				1·55		1·64		
	Pitch	$2\frac{1}{4}$	$2\frac{1}{4}$				$2\frac{1}{2}$		$2\frac{5}{8}$		
	Pitch / Diameter	2·40	2·40				2·35		2·33		
	Strength %	45 *r* 58 *p*	45 *r* 58 *p*				52 *r* 57 *p*		56 *r* 57 *p*		
$\frac{3}{4}$	Diameter	1	1		1		$1\frac{1}{8}$	$1\frac{1}{8}$			
	Diameter / Thickness	1·33	1·33		1·33		1·50	1·50			
	Pitch	$2\frac{1}{2}$	$2\frac{1}{2}$		$2\frac{1}{4}$		$2\frac{5}{8}$	$2\frac{1}{2}$			
	Pitch / Diameter	2·50	2·50		2·25		2·33	2·22			
	Strength %	42 *r* 60 *p*	42 *r* 6[illegible] *p*		47 *r* 56 *p*		50 *r* 57 *p*	53 *r* 55 *p*			

SINGLE-RIVETED LAP-JOINTS—*continued.*

Thickness of Plate.	Dimensions and Ratios.	Authority.								
		A	B	C	D	E	F	G	H	I
$\frac{13}{16}$	Diameter	$1\frac{1}{8}$							$1\frac{1}{4}$	
	$\frac{\text{Diameter}}{\text{Thickness}}$	1·38							1·54	
	Pitch	$2\frac{1}{2}$							$2\frac{7}{8}$	
	$\frac{\text{Pitch}}{\text{Diameter}}$	2·22							2·30	
	Strength %	49 *r* 55 *p*							53 *r* 57 *p*	
$\frac{7}{8}$	Diameter	$1\frac{1}{8}$							1	$1\frac{3}{8}$
	$\frac{\text{Diameter}}{\text{Thickness}}$	1·29							1·14	1·57
	Pitch	$2\frac{1}{2}$							$2\frac{1}{2}$	3
	$\frac{\text{Pitch}}{\text{Diameter}}$	2·22							2·50	2·18
	Strength %	45 *r* 55 *p*							36 *r* 60 *p*	54 *p* 57 *r*
$\frac{15}{16}$	Diameter	$1\frac{3}{16}$			$1\frac{1}{8}$					
	$\frac{\text{Diameter}}{\text{Thickness}}$	1·27			1·20					
	Pitch	$2\frac{5}{8}$			$2\frac{1}{2}$					
	$\frac{\text{Pitch}}{\text{Diameter}}$	2·21			2·22					
	Strength %	45 *r* 55 *p*			42 *r* 55 *p*					
1	Diameter	$1\frac{1}{4}$		1	$1\frac{1}{8}$					
	$\frac{\text{Diameter}}{\text{Thickness}}$	1·25		1·00	1·12					
	Pitch	$2\frac{3}{4}$		$2\frac{1}{4}$	$2\frac{1}{2}$					
	$\frac{\text{Pitch}}{\text{Diameter}}$	2·20		2·25	2·22					
	Strength %	45 *r* 55 *p*		35 *r* 56 *p*	40 *r* 55 *p*					
$1\frac{1}{8}$	Diameter	$1\frac{3}{8}$		$1\frac{1}{8}$						
	$\frac{\text{Diameter}}{\text{Thickness}}$	1·22		1·00						
	Pitch	3		$2\frac{3}{8}$						
	$\frac{\text{Pitch}}{\text{Diameter}}$	2·18		2·11						
	Strength %	44 *r* 54 *p*		37 *r* 53 *p*						

Double-Riveted Lap-Joints.—*Dimensions all in Inches.*

N.B. The "Spacing" in this Table means the distance between the Pitch Lines of the two rows of rivets.

Thickness of Plate.	Dimensions and Ratios.	Authority.								
		A	B	C	D	E	F	H	I	J
$\frac{5}{16}$	Diameter	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$	$\frac{5}{8}$			
	$\frac{\text{Diameter}}{\text{Thickness}}$	2·00	2·00	2·00	2·00	2·00	2·00			
	Pitch	$2\frac{1}{8}$	$2\frac{1}{4}$	$2\frac{1}{2}$	$2\frac{1}{4}$	$2\frac{3}{8}$	$2\frac{1}{8}$			
	$\frac{\text{Pitch}}{\text{Diameter}}$	3·40	3·60	4·00	3·60	3·80	3·40			
	Spacing	$1\frac{1}{2}$	$1\frac{3}{4}$	$1\frac{5}{8}$	$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{4}$			
	$\frac{\text{Pitch}}{\text{Spacing}}$	1·42	1·29	1·54	1·80	1·90	1·70			
	Strength %	71 *p* 92 *r*	72 *p* 87 *r*	75 *p* 79 *r*	72 *p* 87 *r*	74 *p* 83 *r*	71 *p* 92 *r*			
$\frac{3}{8}$	Diameter	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{3}{4}$			$\frac{3}{4}$	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{11}{16}$
	$\frac{\text{Diameter}}{\text{Thickness}}$	1·67	2·00	2·00			2·00	1·67	1·83	1·83
	Pitch	$2\frac{1}{8}$	$2\frac{1}{2}$	$2\frac{1}{2}$			$2\frac{5}{8}$	$2\frac{1}{4}$	$2\frac{11}{16}$	$2\frac{11}{16}$
	$\frac{\text{Pitch}}{\text{Diameter}}$	3·40	3·33	3·33			3·50	3·60	3·91	3·91
	Spacing	$1\frac{1}{2}$	2	$1\frac{5}{8}$			$1\frac{1}{2}$		$1\frac{1}{16}$	$1\frac{1}{16}$
	$\frac{\text{Pitch}}{\text{Spacing}}$	1·42	1·25	1·54			1·75		2·53	2·53
	Strength %	71 *p* 77 *r*	70 *p* 94 *r*	70 *p* 94 *r*			71 *p* 90 *r*	72 *p* 73 *r*	74 *p* 74 *r*	74 *p* 74 *r*
$\frac{7}{16}$	Diameter	$\frac{11}{16}$	$\frac{7}{8}$		$\frac{3}{4}$		$\frac{13}{16}$			$\frac{13}{16}$
	$\frac{\text{Diameter}}{\text{Thickness}}$	1·57	2·00		1·71		1·86			1·86
	Pitch	$2\frac{1}{4}$	$2\frac{3}{4}$		$2\frac{1}{2}$		$2\frac{7}{8}$			$3\frac{1}{8}$
	$\frac{\text{Pitch}}{\text{Diameter}}$	3·27	3·14		3·33		3·54			3·85
	Spacing	$1\frac{5}{8}$	$2\frac{1}{4}$		$1\frac{1}{2}$		$1\frac{5}{8}$			$1\frac{1}{4}$
	$\frac{\text{Pitch}}{\text{Spacing}}$	1·38	1·22		1·67		1·77			2·50
	Strength %	69 *p* 75 *r*	68 *p* 100 *r*		70 *p* 81 *r*		72 *p* 82 *r*			74 *p* 76 *r*
$\frac{1}{2}$	Diameter	$\frac{3}{4}$	$\frac{7}{8}$			$\frac{13}{16}$	$\frac{7}{8}$	$\frac{3}{4}$		$\frac{15}{16}$
	$\frac{\text{Diameter}}{\text{Thickness}}$	1·50	1·75			1·62	1·75	1·50		1·87
	Pitch	$2\frac{1}{2}$	$2\frac{3}{4}$			2	$3\frac{1}{8}$	$2\frac{1}{2}$		$3\frac{9}{16}$
	$\frac{\text{Pitch}}{\text{Diameter}}$	3·33	3·14			2·46	3·57	3·33		3·80
	Spacing	$1\frac{3}{4}$	$2\frac{1}{4}$			$1\frac{1}{4}$	$1\frac{3}{4}$			$1\frac{3}{8}$
	$\frac{\text{Pitch}}{\text{Spacing}}$	1·43	1·22			1·60	1·79			2·59
	Strength %	70 *p* 71 *r*	68 *p* 87 *r*			59 *p* 104 *r*	72 *p* 77 *r*	70 *p* 71 *r*		74 *p* 77 *r*

DOUBLE-RIVETED LAP-JOINTS—*continued.*

Thickness of Plate.	Dimensions and Ratios.	Authority. A	B	D	E	F	G	H	I	J
$\frac{9}{16}$	Diameter	$\frac{13}{16}$	$\frac{15}{16}$	$\frac{7}{8}$	$\frac{13}{16}$	$\frac{15}{16}$				1
	Diameter / Thickness	1·44	1·67	1·55	1·44	1·67				1·78
	Pitch	$2\frac{5}{8}$	3	$2\frac{3}{4}$	2	$3\frac{3}{8}$				4
	Pitch / Diameter	3·23	3·20	3·14	2·46	3·60				4·00
	Spacing	$1\frac{7}{8}$	$2\frac{1}{4}$	$1\frac{3}{4}$	$1\frac{1}{4}$	$1\frac{7}{8}$				$1\frac{9}{16}$
	Pitch / Spacing	1·40	1·33	1·57	1·60	1·80				2·56
	Strength %	69 *p* 70 *r*	69 *p* 82 *r*	68 *p* 78 *r*	59 *p* 92 *r*	72 *p* 73 *r*				70 *r* 75 *p*
$\frac{5}{8}$	Diameter	$\frac{7}{8}$	$\frac{15}{16}$			1		$\frac{7}{8}$		
	Diameter / Thickness	1·40	1·50			1·60		1·40		
	Pitch	$2\frac{3}{4}$	3			$3\frac{5}{8}$		3		
	Pitch / Diameter	3·14	3·20			3·62		3·43		
	Spacing	2	$2\frac{1}{4}$			2				
	Pitch / Spacing	1·37	1·33			1·81				
	Strength %	68 *p* 70 *r*	69 *p* 74 *r*			69 *r* 72 *p*		64 *r* 71 *p*		
$\frac{11}{16}$	Diameter	$\frac{15}{16}$	$\frac{15}{16}$			$1\frac{1}{16}$				
	Diameter / Thickness	1·36	1·36			1·55				
	Pitch	$2\frac{7}{8}$	3			$3\frac{7}{8}$				
	Pitch / Diameter	3·07	3·20			3·65				
	Spacing	$2\frac{1}{8}$	$2\frac{1}{4}$			$2\frac{1}{8}$				
	Pitch / Spacing	1·35	1·33			1·82				
	Strength %	67 *p* 70 *r*	67 *r* 69 *p*			67 *r* 73 *p*				
$\frac{3}{4}$	Diameter	1	1	1		$1\frac{1}{8}$	$1\frac{1}{8}$			
	Diameter / Thickness	1·33	1·33	1·33		1·50	1·50			
	Pitch	3	3	$3\frac{1}{4}$		$4\frac{1}{8}$	$3\frac{5}{8}$			
	Pitch / Diameter	3·00	3·00	3·25		3·67	3·22			
	Spacing	$2\frac{1}{4}$	$2\frac{1}{2}$	2		$2\frac{1}{4}$				
	Pitch / Spacing	1·33	1·20	1·62		1·83				
	Strength %	67 *p* 70 *r*	67 *p* 70 *r*	64 *r* 69 *p*		64 *r* 73 *p*	69 *p* 73 *r*			

Double-Riveted Lap-Joints—*continued.*

Thickness of Plate.	Dimensions and Ratios.	Authority. A	B	C	D	E	F	H	I	K
$\frac{7}{8}$	Diameter	$1\frac{1}{8}$						$1\frac{1}{8}$		
	$\frac{\text{Diameter}}{\text{Thickness}}$	1·29						1·29		
	Pitch	$3\frac{1}{4}$						$3\frac{5}{8}$		
	$\frac{\text{Pitch}}{\text{Diameter}}$	2·89						3·22		
	Spacing	$2\frac{3}{8}$								
	$\frac{\text{Pitch}}{\text{Spacing}}$	1·37								
	Strength%	65 *p* 70 *r*						63 *r* 69 *p*		
$\frac{15}{16}$	Diameter	$1\frac{3}{16}$			$1\frac{1}{8}$			1	$1\frac{1}{4}$	
	$\frac{\text{Diameter}}{\text{Thickness}}$	1·27			1·20			1·07	1·33	
	Pitch	$3\frac{3}{8}$			$3\frac{1}{2}$			$3\frac{1}{2}$	$3\frac{1}{2}$	
	$\frac{\text{Pitch}}{\text{Diameter}}$	2·84			3·11			3·50	2·80	
	Spacing	$2\frac{1}{2}$			$2\frac{1}{4}$					
	$\frac{\text{Pitch}}{\text{Spacing}}$	1·35			1·56					
	Strength%	65 *p* 70 *r*			61 *r* 68 *p*			48 *r* 71 *p*	64 *p* 75 *r*	
1	Diameter	$1\frac{1}{4}$			$1\frac{1}{8}$					
	$\frac{\text{Diameter}}{\text{Thickness}}$	1·25			1·12					
	Pitch	$3\frac{1}{2}$			$3\frac{1}{2}$					
	$\frac{\text{Pitch}}{\text{Diameter}}$	2·80			3·11					
	Spacing	$2\frac{5}{8}$			$2\frac{1}{4}$					
	$\frac{\text{Pitch}}{\text{Spacing}}$	1·33			1·56					
	Strength%	64 *p* 70 *r*			57 *r* 68 *p*					
$1\frac{1}{16}$	Diameter	$1\frac{5}{16}$								$1\frac{5}{16}$
	$\frac{\text{Diameter}}{\text{Thickness}}$	1·24								1·24
	Pitch	$3\frac{5}{8}$								$4\frac{1}{8}$
	$\frac{\text{Pitch}}{\text{Diameter}}$	2·76								3·14
	Spacing	$2\frac{3}{4}$								$2\frac{1}{2}$
	$\frac{\text{Pitch}}{\text{Spacing}}$	1·32								1·65
	Strength%	64 *p* 70 *r*								62 *r* 68 *p*

DOUBLE-RIVETED LAP-JOINTS—*continued.*

Thickness of Plate.	Dimensions and Ratios.	Authority.								
		A	B	C	D	E	F	G	H	I
$1\frac{1}{8}$	Diameter	$1\frac{3}{8}$								
	$\frac{\text{Diameter}}{\text{Thickness}}$	1·22								
	Pitch	$3\frac{3}{4}$								
	$\frac{\text{Pitch}}{\text{Diameter}}$	2·73								
	Spacing	$2\frac{7}{8}$								
	$\frac{\text{Pitch}}{\text{Spacing}}$	1·30								
	Strength %	63 *p* 70 *r*								

APPENDIX II. ON RIVETED JOINTS.

FIRST REPORT TO THE COUNCIL OF THE COMMITTEE ON THE FORM OF RIVETED JOINTS.

(*First issued Nov.* 1879, *and now published by order of the Council.*)

Members of the Committee:—W. Boyd, Esq.; W. S. Hall, Esq.; Prof. A. B. W. Kennedy; R. V. J. Knight, Esq.; Wm. Parker, Esq.; R. H. Tweddell, Esq.; Prof. W. C. Unwin, *Reporter*.

CONTENTS.

IV. EXPERIMENTS ON DIFFERENT FORMS OF RIVETED JOINTS.
- Single-riveted lap joints of iron.
- Single-riveted butt joints of iron.
- Double-riveted lap and butt joints of iron.
- Shearing resistance of iron and steel rivets in steel plates.
- Resistance to tearing of steel lap joints.
- Resistance to tearing of steel butt joints.

APPENDIX I. Bending of Thick Plates.

APPENDIX II. Memorandum of suggestions as to Experiments to be undertaken on Riveted Joints.

The Committee having entrusted to the Reporter the preparation of a preliminary report on the subject which they propose to investigate, he has examined, as far as possible, all papers or memoirs which contain experiments bearing on the subject. A list of such papers and memoirs was prepared at the Institution by the Secretary, and with his assistance copies of most of them were obtained. Abstracts have been made of the whole of the papers enumerated below. Further, all experiments found in these papers have been tabulated in a common form for comparison, and the results reduced to common measures.* These reductions have been carefully made by Mr. Nolet, and it is hoped that they will much facilitate the examination and comparison of the experiments which have thus far been made. The form in which the results are tabulated is a much more comprehensive one than that generally adopted; and to bring previous results, sometimes not very clearly recorded, into this shape has involved a good deal of labour. When this work was about half finished, the Reporter received from Mr. B. B. Stoney an admirable paper on riveted joints,—perhaps, indeed, the best of any experimental paper on the subject,—in which the system of tabulating the results is very similar to that which had been adopted.

The following is a list of all the papers of which abstracts have been made, of all obtainable papers in fact in which original experiments on riveting are to be found. Merely theoretical papers have for the most part been excluded from this list. It still remains

* The units employed throughout this Report are Inches, Tons, and Tons per sq. inch.

to examine papers and treatises in which riveting is treated from the purely theoretical point of view, or in which practical rules and proportions are given. This however may very well be left to a somewhat later stage in the proceedings of the Committee.

List of Original Memoirs on Riveting of which Abstracts have been made. Arranged chronologically, or nearly so.

"Experimental Inquiry into the Strength of Wrought-Iron Plates and their Riveted Joints." By William Fairbairn. Phil. Trans., Part II., 1850, pp. 677–725.

"Riveting and Shearing of Iron." By Edwin Clark. Britannia and Conway Tubular Bridges. Vol. I., Chap. IV., 1850.

"Experiments on Double-Riveted Joints." By I. K. Brunel. Also "Experiments at Woolwich." By W. Bertram. Given in "Recent Practice in the Locomotive Engine." By D. K. Clark, 1858. Also "Rules and Tables." By D. K. Clark, 1878.

"Lloyd's Experiments upon Iron Plates, and modes of Riveting applicable to the construction of Iron Ships." By Thomas Chapman. Trans. Inst. Naval Architects, 1860.

"Jointing and Riveting Iron Ships." By John Grantham. Trans. Inst. Naval Architects, 1862.

"The application of Iron to the purposes of Naval Construction." By William Fairbairn. Society of Arts, Vol. XIII., Nov. 1864, p. 20.

Maynard's Experiments on Punched and Drilled Plates. Letter in "The Engineer." 1864.

Rankine on Shearing Resistance of Rivets. "The Engineer." 1864.

"On Single and Double-Riveted Joints." By Thomas Baldwin. Trans. Soc. of Engineers, 1866, pp. 150–190.

"Wrought Iron Bridges and Roofs." By W. C. Unwin. Note on Fairbairn's Experiments, 1868.

"On the treatment of Steel Plates." By Henry Sharp. Trans. Inst. Naval Architects, 1868, pp. 10–29.

"On some Improvements in the Scantlings of Iron Steam Vessels." By John Price. Trans. Inst. of Engineers in Scotland, 1869–1870.

"Collectaneen über einige zum Brücken- und Maschinenbau verwendete Materialien." Von A. von Kaven. Hannover, 1869.

John Cochrane, Remarks on the effects of Punching and Drilling. Proc. Inst. Civil Engineers, Vol. XXX., 1870, p. 265.

"Studies of Iron Girder Bridges." By Prof. Calcott Reilly. Proc. Inst. Civil Engineers, Vol. XXIX., 1870. Contains considerations on the arrangement of rivets in complicated joints.

"The Strength and Proportions of Riveted Joints." By W. R. Browne. Proc. Inst. Mech. Engineers, 1872.

"Drilling *v.* Punching." Letter in "The Engineer." By W. R. Browne. Nov. 1872, p. 362.

"Experiments on Riveted Joints and Steel Plates." By David Kirkaldy. For the Bolton Iron and Steel Company, London, 1872.

"On the Durability and Preservation of Iron Ships, and on Riveted Joints." By Sir William Fairbairn. Proc. Roy. Soc. 1873.

"Triple Riveting." By W. R. Browne. 1873.

"On the Strength of Cylindrical Boiler Shells." By Hector MacColl. Trans. Inst. of Engineers in Scotland, 1874–75, pp. 111–152.

"On Iron and Steel for Ship-building." By N. Barnaby. Trans. Inst. of Naval Architects, 1875, pp. 131–146.

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"The Lancashire Boiler." By Lavington E. Fletcher. Proc. Inst. Mech. Engineers, 1876.

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"The Strength of Riveted Joints." By R. B. Longridge. "The Engineer." Feb. 23, 1877.

"Experiments relative to Steel Boilers." By W. Boyd. Proc. Inst. Mech. Engineers, April 1878.

"On Steel for Ship-building." By B. Martell. Trans. Inst. Naval Architects, 1878, pp. 1–32.

"On the Use of Steel for Marine Boilers." By W. Parker. Trans. Inst. Naval Architects, 1878.

"Progress of Steam Shipping." Proc. Inst. Civil Engineers, Vol. LI., p. 131. (Experiments communicated by R. V. J. Knight.)

"Steam Boilers for High Pressure." Proc. Inst. Civil Engineers, Vol. LIV., p. 161. (Experiments communicated by R. V. J. Knight.)

"Experiments on the Shearing of Steel Rivets." By Max Eyth. MS.

"On the connection of Plates of Iron and Steel in Ship-building, especially such as were subject to sudden Tensile Strains." By N. Barnaby. Trans. Inst. Engineers in Scotland, Vol. IX., pp. 153–164.

Experiments communicated by Messrs. Easton and Anderson. MS.

"Iron and Mild Steel." By D. Adamson. Journal of Iron and Steel Institute, 1878, pp. 392, 393.

"The Use of Steel in Naval Construction." Paper read before the Iron and Steel Institute. By N. Barnaby, C.B. "Engineering." May 16, 1879.

"Iron and Mild Steel." Paper read before the Iron and Steel Institute. By D. Adamson. "Engineering." May 9, 1879.

"Experiments referring to the use of Iron and Steel in High-Pressure Boilers." By D. Greig and M. Eyth. Proc. Inst. Mech. Engineers, June 1879.

(I.) SHORT ACCOUNT OF THE HISTORY OF EXPERIMENTS ON RIVETING.

Before discussing the details of experiments on riveting, it may be interesting to give a short account of the more important memoirs in the preceding list. The earliest published experiments on riveted joints, and probably the first experiments on the strength of riveting ever made, are contained in the memoir by Sir W. Fairbairn in the Transactions of the Royal Society. The experiments in this paper have probably had more influence in determining the proportions adopted in practice for riveted joints than any others. The author first determined the tenacity of the iron, and found, for the kinds of iron experimented on, a mean tenacity of 22·5 tons per sq. in. with the stress applied in the direction of the fibre, and 23 with the stress across it. That the plates were found stronger when loaded in a direction at right angles to that in which they were rolled is probably due to some error in marking the plates. Taking the average tenacity of the joints tested, he obtained the following results:—

	Breaking Stress in tons per sq. in.
Unpunched plate	23·43
Double-riveted joints	23·94
Single-riveted joints	18·57

That the tenacity of the iron was virtually reduced by about 20 per cent. in single-riveted joints, and not at all in double-riveted joints, is a result which is of the greatest importance; and the bearing of this on the design of joints does not appear to have received full consideration till a much later period. Making certain empirical

allowances, Sir W. Fairbairn adopted the following ratios as expressing the relative strength of riveted joints :

Solid plate	100
Double-riveted joint	70
Single-riveted joint	56

These well-known ratios are quoted in most treatises on riveting, and are still sometimes referred to as having a considerable authority. It is singular however that Sir W. Fairbairn does not appear to have been aware that the proportion of metal punched out in the line of fracture ought to be different in properly designed double and single-riveted joints. These celebrated ratios would therefore appear to rest on a very unsatisfactory analysis of the experiments on which they are based. Sir W. Fairbairn also gives a well-known table of standard proportions for riveted joints. It is not very clear how this table has been computed, and it gives proportions which make the ratio of tearing to shearing area different for different thicknesses of plate. There is no good reason for this.

About the same time some experiments on the shearing resistance of rivets, and on the friction of riveted plates, were published in Mr. Edwin Clark's Treatise on the Britannia and Conway Bridges.

Some experiments by Mr. Bertram at Woolwich Dockyard were published and discussed by Mr. D. K. Clark in 1860. They do not appear to be very reliable. Taking the single-riveted joints, riveted by hand, the following numbers are given :—

Thickness of plate . . .	$\frac{1}{2}$ inch	$\frac{7}{16}$ inch	$\frac{3}{8}$ inch
Net ultimate tensile strength of joint in per cent. of that of solid plate .	40	50	60

It must follow from these figures that a joint in a $\frac{7}{16}$-inch plate is stronger than one in a $\frac{1}{2}$-inch plate, not only proportionately but absolutely. Similarly, that a $\frac{3}{8}$-inch plate joint is absolutely stronger than a $\frac{7}{16}$-inch plate joint. The absolute strengths would be as follows, taking the strength of 1 sq. in. as 100 :—

Thickness of plate . . .	$\frac{1}{2}$ inch	$\frac{7}{16}$ inch	$\frac{3}{8}$ inch
Strength of joint, per cent. . .	20	21·9	22·5

It is impossible to suppose that the strength of the joint increases as the plate is made thinner, and yet these results have been republished in 1878 without remark.

In 1866 Mr. Baldwin (Transactions Society of Engineers) pointed out the errors in Fairbairn's standard proportions for riveted joints. He then calculated a new table for single and double-riveted joints, making the proportions such that the tearing and shearing areas were equal. An interesting discussion followed the reading of this paper, in which Mr. Barnaby spoke strongly of the great reduction of the tenacity of the iron in riveted joints, in consequence either of injury done in punching or of the unequal distribution of stress on the metal between the rivets. Some of the tenacities given by Mr. Barnaby are so low that we may fairly suspect some defect in the mode of experimenting; but he first definitely pointed to the great diminution of tenacity in joints, when compared with that of solid plates, as a matter seriously affecting the proportions which should be adopted.

A paper by Mr. Henry Sharp (Transactions Inst. Naval Architects, 1868) contains the earliest published experiments on steel riveted joints. Mr. Sharp specially drew attention to the injury done to plates by punching, the deterioration of tenacity being greater the harder the material of the plates. He showed also that if the plates were annealed after punching their original strength was restored.

The tendency of the rivet and plate to crush each other was first pointed out by Mr. J. H. Latham ("Construction of Wrought Iron Bridges," p. 17, 1858). He also first defined the bearing surface of a rivet, and assumed, on rather theoretical and not very satisfactory grounds, that the stress per unit of bearing surface should not exceed the stress per unit of tearing section. The question of the proper limit of crushing pressure on the bearing surface of the rivet has remained unsolved to the present time, and in most treatises on riveting it is not taken into consideration.

In some lectures at Chatham in 1868 the present writer pointed out that in Fairbairn's experiments there is some relation between the tenacity of the plate and the crushing pressure of the rivets on

the plates. Arranging the experiments in the order of the pressure per sq. in. of bearing surface, it is seen that the tenacity increases uniformly with the bearing surface, and reaches a maximum in those cases where the bearing surface in the rivet on the plate is equal to the tearing area of the plate. This would appear to indicate that part of the diminution in tenacity of the iron in the joints tested was due, not to any injury to the plate in punching, but to the crushing action of the rivet before the final fracture of the joint.

The strength and proportions of riveted joints of iron were discussed in an admirable paper by Mr. Walter R. Browne, communicated to the Institution of Mechanical Engineers in 1872. This is the first paper in which full attention is given to arranging the proportions so as to prevent an excessive pressure per unit of bearing surface. It is the first paper also in which allowance is made for the reduction of the tenacity in joints as compared with solid plates, especially in the case of single-riveted joints. The following are the limiting stresses for iron, selected from an examination of experiments:—

	Tons per sq. in.
Crushing resistance per sq. in. of bearing surface—	
Joints with one cover	40
„ two covers	42·9
Shearing resistance—	
Rivets in single shear	22
„ „ double shear	21
Tearing resistance—	
Single-riveted joints punched	18
„ „ „ drilled	22
Double-riveted joints punched	19½
„ „ „ drilled	22

Very simple rules are given based on these limits; but it may be observed that they assume the rivet diameter to be twice the plate thickness, a proportion not usual in practice for thick plates. If a less simple proportion is adopted, the rules for the proportions of the joints necessarily become more complicated. Some experiments are given in this paper in which a very low tenacity of the joints was

observed. This is ascribed to the rather high crushing pressure of the rivets on the plates, which caused elongation of the holes and consequent unequal distribution of stress on the section of fracture. The results are however somewhat exceptional. In a letter to "The Engineer," in 1872, Mr. Browne quoted some experiments made in America, showing considerable loss of tenacity in drilled and punched plates, especially in the former; and gave a satisfactory explanation of one cause of loss of strength in plates having a hole, namely the disturbance of the equal distribution of stress on sections near the hole.

In 1873 a second paper on riveted joints was communicated to the Royal Society by Sir W. Fairbairn, chiefly relating to the relative advantages of punching and drilling. The experiments in this paper show that the shearing resistance of rivets in drilled holes is rather less than that of rivets in punched holes, which appears to be due to the sharp edge of the drilled hole. By definitely rounding the edge of the hole, a greater shearing resistance is obtained than that of rivets in punched holes.

	Shearing resistance of rivet in tons per sq. in.
Rounded holes	21·52
Punched holes	20·95
Drilled holes	19·23

In some experiments made by Mr. Kirkaldy for the West Cumberland Steel Works, iron rivets in steel plates sheared at 15 to 19 tons per sq. in.

In a paper communicated by Mr. Barnaby to the Institute of Naval Architects in 1875 some experiments were given, showing that the tenacity of steel plates might be reduced from 31 or 32 tons to $14\frac{1}{2}$ tons per sq. in. by the injury done in punching.

In the Transactions of the Royal Irish Academy for 1875 is an extremely interesting paper by Mr. B. B. Stoney on single-riveted joints. The limits of stress obtained are as follows:—

	Tons per sq. in.
Crushing resistance of bearing surface—	
In the strongest joints	30
Shearing strength—	
Drilled holes, single-riveting	18·28
Punched holes, „ „	19·16

In double-riveted joints a somewhat greater shearing resistance was found.

Loss of tenacity in the joints—	Per cent.
In drilled plates, mean loss	2
„ punched „ „ „	11·45

Some results communicated by Mr. Riley to the Institute of Naval Architects in 1876 showed no loss of strength in bars of Landore steel punched and unannealed.

Mr. Kirk communicated experiments on the effect of punching iron and steel plates to the Institute of Naval Architects, in 1877. These experiments showed that, while punching in all cases diminished the tenacity of iron plates, the loss of strength was much less when the hole in the die-block was larger than the punch, than when they were of the same size. With steel plates the loss of strength by punching was much greater, but the same influence of the size of hole in the die-block was observed.

In "The Engineer" for Feb. 23, 1877, is an account of some interesting experiments by Mr. R. B. Longridge. Unfortunately only "nominal" and not real dimensions of the plates and rivets are given. These experiments tended to show that Fairbairn's estimate of the strength of riveted joints was too high. For single-riveted joints, in which the plates broke, the strength of the joint ranged from 38·9 to 40·7 per cent. of the strength of solid plate when the plates were unannealed, and was 45·7 per cent. in an annealed plate. In joints in which the rivets sheared, the strength ranged from 39 to 44 per cent. of the strength of the solid plate, one joint giving (unless there is a misprint) 50·6 per cent. In some experiments in which the plates are described as "breaking joint" the percentage was higher. In experiments with double-riveted lap joints, all gave way by tearing the plates except two. The joint had from 54·5 to 66·1 per cent. of the strength of solid plate. With single-riveted butt joints, all gave way by tearing the plates, and the strength was from 51·5 to 58·5 per cent. of that of solid plate. With double-riveted butt joints, all but one gave way by tearing the plates, and the strength was from 61·6 to 67 per cent. of that of solid plate. It

is stated that chain riveting proved to be stronger than zigzag riveting, but it is not quite clear from the Tables how this result is arrived at.

Experiments relative to steel boilers were communicated by Mr. Boyd to the Institution of Mechanical Engineers in 1878. In two of the experiments here given it appeared that punching diminished the tenacity of steel plates by 35 and 51 per cent., while drilling reduced it only 2 per cent. Annealing appeared to restore the strength of the punched plates. In the discussion on this paper Dr. Siemens mentioned experiments on punched steel plates in which the strength appeared to be increased by punching, and spoke of the helical punch as likely to diminish the liability to injure the plate in punching. This was confirmed by experiments given by Mr. Tweddell.

An extensive series of experiments is contained in a paper by Mr. Martell on steel for ship-building, in the Transactions of the Institute of Naval Architects for 1878. The mean values of the breaking stress in these experiments were as follows:—

	Tons per sq. in.
Iron plates, holes punched, tore in line of rivet holes, at	17·9
Iron rivets in steel plates, double chain riveted, sheared at	16·7
Iron rivets in steel plates, the rivets being zigzag, sheared at	19·2
Steel plates with punched holes and steel rivets, not annealed, gave way by tearing the plates or shearing the rivets at	22·5

With thin steel plates the injury due to punching appeared to be less than with iron plates. In the case of plates above $\frac{8}{10}$ inch thick the loss of strength due to punching was 20 to 23 per cent. for iron, and 20 to 33 per cent. for steel. By annealing the lost strength was restored. Steel was injured for a very small distance round the hole, so that by rimering out an annulus of metal $\frac{1}{8}$ to $\frac{1}{16}$ inch thick the injured part was removed. In drilled plates there was no appreciable loss of strength. Plates punched with a spiral punch were $2\frac{1}{2}$ tons per sq. in. stronger than when punched with an ordinary punch.

The most careful examination of the way in which punching injures plates has been made by M. Barba, whose experiments are described in a Treatise on the Use of Steel (1875). M. Barba shows that when a punched bar is broken by tensile stress, the width of the bar, relatively to the diameter of the hole, influences the apparent tenacity. The tenacity diminishes, in these experiments, as the width of the bar for a given diameter of hole increases. From this he infers that the loss of tenacity is not due to any cracking produced by the punch, or to a reduction of tenacity in the neighbourhood of the hole. The effect of punching is to alter the elasticity, or to diminish the power of elongating, in a narrow annulus round the hole. This causes an unequal distribution of stress, and fracture begins at the rivet-hole. By removing an annulus 0·04 inch thick round the hole the effect of punching is neutralised. With both iron and steel plates similar results were obtained.

The Committee have received a copy of a Report by Mr. W. Parker and Mr. John, made in 1878 to Lloyd's Committee, on the effect of punching and drilling. The experiments on which this Report is based were made at the Chain Testing Works at Saltney. These experiments showed that thin steel plates lost comparatively little from punching, but that in thick plates the loss was very considerable. The following Table gives the results for plates punched and not annealed or rimered :—

Thickness of Plates.	Material of Plates.	Loss of tenacity per cent.
$\frac{1}{4}$	Steel	8
$\frac{3}{8}$	,,	18
$\frac{1}{2}$	,,	26
$\frac{3}{4}$	,,	33
$\frac{3}{4}$	Iron	18 to 23

The effect of increasing the size of the hole in the die block is shown in the following Table :—

Total taper of Hole in Plate. Inches.	Material of Plates.		Loss of tenacity due to punching per cent.
$\frac{1}{16}$	Steel		17·8
$\frac{1}{4}$	,,		12·3
$\frac{1}{3}$	,,	(Hole ragged)...	24·5

The plates were from 0·675 to 0·712 inch thick.

It was observed that the effect of punching was not only to reduce the tenacity, but also to diminish the elongation before fracture, and to cause the fracture to become crystalline instead of silky. This is quite accordant with Barba's views. When $\frac{7}{8}$-in. punched holes were rimered out to $1\frac{1}{8}$ in. diameter, the loss of tenacity disappeared, and the plates carried as high a stress as drilled plates. Annealing also restores to punched plates their original tenacity. Some of these experiments are given in a paper read before the Institute of Naval Architects in 1878.

Mr. D. Adamson has found that, while a series of small holes in a bar does not diminish but rather increases the tenacity of the metal left, a large hole may cause a serious reduction of strength, particularly with material which elongates little under strain. This Mr. Adamson explains as due to the interruption of the lines of force by the presence of the hole. The following results obtained by him are more conveniently given here than later :—

	Apparent Tenacity in tons per square inch.	
1. Solid plate	29·46	All of same material.
2. One hole	27·00	
3. One hole, with turned pin driven in	28·57	
4. Two smaller holes	29·01	
5. Two holes (broke in solid part of plate)	63·70	
6. Iron tested across the grain, one hole (broke through hole) . .	17·41	Same material.
7. The same, two smaller holes (broke in solid part of plate) . .	19·64	
8. Steel (same material as in 1), one large hole	27·522	Same material.
9. The same, two smaller holes . .	30·357	
10. Solid plate	58·704	All of same material.
11. One hole	56·941	
12. Two smaller holes	65·624	

In a paper communicated to the Iron and Steel Institute in 1879, Mr. Barnaby has given a series of experiments specially intended to determine the influence of punching on iron and steel. He has found that iron suffers more in punching when the holes are near the

edge than when further removed; but in mild steel the material suffers less when the hole is one diameter from the edge than when so distant that there is no bulging of the edge. Specimens were prepared with two holes punched in each, and these were shaped in the slotting machine so that the distance of the holes from the edge should always be one rivet diameter, and the pitch between the holes that usual in ship-riveting. In some cases the bar was shaped to the required width before punching; in others the holes were punched and the plate shaped afterwards. In the latter case any bulging of the edge of the plate during punching was prevented by the distance of the hole from the side of the plate.

	Apparent Tenacity. Tons per sq. in.		
	Unpunched plate.	Punched before shaping.	Punched after shaping.
Open hearth steel .	27·6	23·7	24·5
Converter steel . .	27·5	21·7	24·8
Best best iron . .	21·5	19·0	17·7

The following experiments were on plates above ½ inch thick, butt jointed and treble riveted:—

	Apparent Tenacity. Tons per sq. in.	
	Annealed.	Not annealed.
Counter-sunk points—		
Open hearth steel	30·6	29·84
Converter steel	30·2	21·80
Best best iron	—	19·90
Snap points—		
Open hearth steel	28·6	21·20
Converter steel	26·9	15·25
Best best iron	—	18·30

The counter-sinking was not carried through the plate, so that a part of the metal strained in punching was left. Comparing the tenacities with those of solid unpunched plates in the previous Table, a gain of strength for the riveted joints is in some cases observed. This Mr. Barnaby ascribes to the friction of the riveted joint.

To get rid completely of the injury done in punching, Mr. Barnaby proposes in future to punch the holes ⅛ inch less in diameter than the rivet, and to enlarge the hole when countersinking. Snap riveting is only employed by him for subordinate parts.

It may be presumed that the low apparent tenacity with unannealed plates and snap points is due to the amount of injured metal being greater than with countersunk points. But it is not obvious why the tenacity with annealed plates is less for snap than for countersunk points.

An exceedingly complete and extensive series of experiments on riveting is described in a paper by Mr. David Greig and Mr. Max Eyth, read before the Institution of Mechanical Engineers while this report was in preparation. The first experiments related to Taylor's Yorkshire rivet iron, and to Brown & Co.'s mild rivet steel. The tensile strength of the iron was 22·2 tons per sq. in., and of the steel 28·8 tons per sq. in. The shearing resistance of the iron was 19 tons, and that of the steel 22·1 tons. Some plates riveted together were then tested, and a somewhat higher shearing resistance was found than for bars not formed into rivets. This is ascribed partly to the rivet being increased in diameter to fill a hole larger than its normal size, partly to the friction of the plates. Experiments on the effect of the riveting pressure on the strength of the rivet seemed to show some increase of resistance as the pressure is greater. This may be due to friction, but the matter requires further investigation. The hardening of the rivet is a possible cause of increased resistance of rivets as compared with simple bars, as well as the friction of the plates.

Experiments were made on riveted joints, the plates being $\frac{3}{8}$ in. thick, the rivets $\frac{5}{8}$ in. diam., and the holes drilled $\frac{11}{16}$ in. diameter. Solid plates broke with a mean resistance as follows :—

Cammell's Iron	22·29	tons per sq. in.
Brown's Iron	22·26	,,
Mean	22·27	,,
Cammell's Steel	25·49	,,
Brown's Steel	26·18	,,
Mean	25·83	,,

Experiments on lap joints with punched and drilled holes showed that with drilled iron plates the apparent tenacity of the plates was only 84·1 per cent. of that of undrilled plates, while the apparent

shearing resistance of the rivets was 103 per cent. of the resistance of the rivet iron. The punched iron plates gave way with an apparent tenacity 75·5 per cent. of that of the unpunched plate. The steel joints all gave way by shearing the rivets, the shearing resistance for drilled holes being 108 per cent. of the shearing resistance of the steel bar as given above, and that for punched holes being 115 per cent. This confirms Fairbairn's experiments as to the greater strength of rivets in punched holes.

Twelve lap joints riveted in different ways gave the following results:—

	Ratio of Strength of Joint to that of Solid Plate.		Ratio of Apparent Tenacity to Tenacity of Plate.
Hand riveted, iron joints	·465	...	·825
Hydraulic riveted, iron joints	·539	...	·896
Steam riveted, iron joints	·509	...	·846

All the steel joints gave way by shearing the rivets, the seam being 49, 58, and 54 per cent. of the strength of solid plate, with hand, steam, and hydraulic riveting respectively. The apparent shearing resistance was 95, 112, and 107 per cent. of the shearing resistance of the rivet steel tested as a bar.

Specimens of iron lap joints with $\frac{3}{4}$ instead of $\frac{5}{8}$ in. rivets, gave a somewhat greater resistance, the joint having 57·6 per cent. of the strength of solid plate.

Double-riveted lap joints were then tested. Iron joints, which broke by tearing the plate or shearing the rivets, had 65 per cent. of the strength of solid plate. Steel specimens broke by shearing the rivets, the strength of the joint being 70 per cent. of that of the solid plate.

Single-riveted butt joints of iron gave way at a strain equal to 47 per cent. of that which would have broken solid plate. The strength is about the same as that of single-riveted lap joints, as might be expected. The steel joints had 56 per cent. of the strength of solid plate, and gave way by shearing as before. Double-riveted butt joints also gave nearly the same results as double-riveted lap joints. Butt joints with double covers gave a somewhat higher resistance, which is attributed to the less bending of the plates and to the greater

friction between them. It is however very difficult to see that the friction can affect the tenacity of joints which give way, as these did, by tearing the plates. The strength of these seams was from 60 to 68 per cent. of that of solid plate.

Experiments are then given on the strength of stayed surfaces and of riveted boilers tested by hydraulic pressure. In these latter the seams began to leak at a comparatively moderate pressure, and the pumping power was inadequate to raise the pressure to anything like the bursting pressure of the boiler. In steam-boiler explosions the action is too sudden for such a relief of pressure by leakage to occur.

(II.) STRAINING ACTION ON RIVETED JOINTS.

A riveted joint is in a certain sense an imperfect part of a structure. It cannot be so designed as to be uniformly strained throughout. It has always certain surfaces markedly weaker than the rest, at which consequently deterioration of the material, or fracture by the action of the load, is liable to occur. These surfaces of weakness are so related that in general the increase of one involves a diminution of the other. The joint therefore which will carry the greatest load before fracture will be that in which the stress reaches the breaking limit for each of these surfaces simultaneously. Since the rivet section can in general be increased only at the expense of the plate section, in the strongest joint the rivet and plate will reach their breaking point under the same load. It would seem therefore that the proportions of a riveted joint could be determined by the ordinary rules of applied mechanics, without the need of experiment. That this is not so is probably mainly due to a second condition of imperfection in riveted joints. To apply the ordinary rules for the strength of materials to riveted joints, it is necessary that the distribution of the stresses on the surfaces of weakness should be known. If those stresses were distributed in the same way as in an ordinary bar tested for tension or shearing, the problem would be simple. But in fact the stresses are not similarly distributed, and the law of their distribution is unknown. Consequently the average stress on the surface of fracture of a riveted joint, when broken by a load, is not the same as

in an ordinary test bar, and needs to be determined by special experiments. Further, it may be different for different forms of joint. This average stress, always less than the maximum stress which causes fracture, is here termed the apparent breaking stress. Hence the chief object of experiments on riveted joints is to determine the apparent breaking stresses, (1) for the different surfaces at which each joint may fracture, (2) for the different forms of joint.

In certain cases allowance may have to be made for progressive deterioration of a joint, by corrosion or otherwise, which reduces the strength in certain directions more than in others. No experiments showing the amount of deterioration in such cases appear to have been made.

Apparent Tenacity of Material.—Let a bar be broken at the plane *a b* of area ω (Fig. 1, Plate 34), by a tension T acting normally to the section.

Then if the stress is uniformly distributed over the section at the moment of fracture, the ratio $\frac{T}{\omega}$ is the real tenacity of the material. But if it is not uniformly distributed, then $\frac{T}{\omega}$ is only the apparent tenacity; and this may be less than the real tenacity to any extent whatever. It may be useful to consider under what conditions the distribution of stress necessarily becomes unequal.

(1) It will cease to be uniform if the resultant P of the load does not pass through the centre of figure of the section. Thus in the case shown in Fig. 2 the stress is a varying stress, which however varies regularly so long as the limit of elasticity is not passed. Some of the discrepancies in the results of experiments on riveted joints are probably due to want of care in ensuring the coincidence of the line of action of the load with the centre line of the joint, in the plane parallel to the surface of the plates. Fig. 2 *a* shows how unequal distribution of stress may arise from this cause. In the longitudinal section of the joint there is probably always deviation of the load from the centre of figure. In lap joints the load has to be transmitted from one plate through the rivet to the other plate; in butt joints from one plate through the rivets to the cover strip, and back to the other plate. In both cases, and especially in the former

case, the eccentricity of the load appears to cause a reduction of strength.

(2) The stress may be rendered unequal by the local action of contiguous material. Thus a bar with square corners (Fig. 3) is known to break with a low apparent tenacity. The unstrained material at *a* prevents the elongation of the contiguous material at *b*, which consequently gets an excessive proportion of the load, and the fracture begins at the corners.

Now in the portion of metal between two rivet holes a similar action probably occurs. The outside fibre *a b* (Fig. 4) has less freedom of elongation than the central fibre *c d*, because it is attached to the comparatively unstrained material behind the rivet. Hence, instead of breaking simultaneously over the whole section, fracture probably begins at the edges of the hole, and then proceeds because the reduction of area causes increase of stress in the part remaining unbroken. This is sometimes shown by the fact that the parts of the plate will not fit after fracture. There appears to be a slight reduction of strength in plates with a hole drilled in them, as compared with solid plates, and this is probably due to the cause now under consideration. It is also probable that this reduction of strength may really be greater than appears in these experiments. Short bars are known to give a higher average tenacity than long bars. Now a bar with a hole drilled in it is virtually a very short bar, and it ought therefore, if there were no cause of diminution of strength, to show a higher tenacity than ordinary test bars. But in fact there is generally a loss of strength.*

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* In some experiments there is a curious apparent increase of strength after drilling. Thus in one of Mr. Stoney's experiments the drilled plate was $7\frac{1}{2}$ per cent. stronger than the undrilled plate. In some experiments by Mr. Parker the plain plate carried 26·4 tons, while a plate punched and annealed carried 31·7 tons. See also the Table of treble-riveted joints given further on. Mr. Adamson also finds that the tenacity through a line of drilled holes is a little greater than the tenacity of the plate before drilling. Discrepancies of this kind may be due to the holes causing fracture at a section stronger per square inch than other parts of the plate. An ordinary test bar breaks at the weakest part of a more or less considerable length of bar.

(3) If the material in the neighbourhood of the surface of fracture is initially (before the application of the load) in an irregularly strained condition, or has in different parts unequal power of elongating, then the stress will not be uniform at the moment of fracture, and the apparent tenacity will be less than the real tenacity. This is the cause of the loss of strength due to punching. By the action of the punch metal is caused to flow laterally into the surrounding metal. This induces initial stresses in an annulus of metal round the hole, and very probably also, as M. Barba thinks, alters its power of elongation. If the power of elongating is diminished in part of the metal, that part gets an excessive proportion of the load, and breaks before the rest is fully strained. The result of either loss of tenacity or loss of ductility is to diminish the apparent tenacity of the metal, to an extent which certainly reaches in some cases 20 to 30 per cent. Fig. 5, Plate 34, shows a possible condition of the bar after punching, the ordinates of the full black curves, measured from the centre line, representing the stresses. Immediately round the hole is an annulus in which the stress is compressive, the compression being due to material forced in. To balance the forces in this ring, an annulus in which the stress is tensile must surround it.

In some experiments there appears to occur a serious diminution in the apparent tenacity of riveted joints when the bearing surface of the rivets on the plates is too small, and when consequently the crushing pressure between the rivet and plate is excessive. It is possible that this is due to an action like that which occurs in punching. The pressure of the rivet may cause a lateral flow of the metal, and alter either the stress or the elasticity of a ring of metal round it. The stress on the tearing section being then unequal, a low apparent tenacity is observed.

(III.) EXPERIMENTS TO DETERMINE DIRECTLY THE BREAKING STRESS.

Tenacity of Iron and Steel Plates.—The following are the principal values of the tenacity of iron and steel in the memoirs of which abstracts have been made:—

Iron.

	Tenacity, Tons per sq. in. With Fibre.		Across Fibre.
Fairbairn . . .	22·5	...	23·0
Roberts (Baldwin's Paper)	17·92		
Parker (Best Best) . .	23·3		
Stoney	18·54		
,, ...	22·00		
,, ...	21·43		
,, ...	24·00		
Fletcher	21·19		
Easton and Anderson .	18·7	...	14·0
,, ,, .	21·5	...	20·5
Barnaby	21·5		
Greig and Eyth . .	22·27		

Steel.

Riley	31·20	...	31·25 Unannealed.
,, ...	28·85	...	28·78 Annealed.
Kirk	28·34		
Boyd	28·7		
Parker	27·89		
Martell	28·93		
Barnaby, Open hearth .	27·6		
,, Converter . .	27·5		
Greig and Eyth . .	25·83		

Where the direction of fracture is not stated, it is assumed that the load was applied in the direction of the fibres. The tenacity of iron is on the average ten per cent. less in a plane perpendicular to the direction of rolling, than in a plane parallel to the direction of rolling: with steel there is no sensible difference.

Apparent Tenacity of Punched and Drilled Plates.—The apparent tenacity of punched and drilled plates must be obtained from

experiments on single plates, with one or more holes in the line of fracture. In experiments on riveted joints there is a certain amount of bending and crushing action, and the diminution of tenacity is greater than that due simply to punching or drilling. Two experimenters, Mr. Cochrane and Mr. Riley, the former testing Lowmoor and ordinary iron, the latter Landore steel, have found that neither punching nor drilling had any sensible effect in altering the tenacity of the metal. In the latter case holes were punched or drilled in the edge of a strip. Probably in that case the compressive action is less than when a hole is made in a wide strip, and consequently the injury to the plate is less. In Mr. Cochrane's experiments the strip was so narrow that it could expand laterally under the action of the punch. The right method in making such experiments would seem to be to form the holes in a wide plate, which is afterwards cut into strips suitable for experiment.

Mr. Stoney has found in three iron plates with drilled holes, a diminution of from 2·6 to 9·2 per cent. of tenacity, and in one plate an increase of 7·5 per cent. Average loss 2·05 per cent.

Mr. Kirk gives some experiments showing that iron and steel plates with drilled holes are stronger than with punched holes; but he does not give the tenacity of the undrilled plate. With a thinner steel plate, $\frac{1}{4}$ in. thick, he appears to have obtained the following results:—

	Tenacity. Unannealed.	Tenacity. Annealed.
Undrilled plate	29·74	29·30
Drilled plate	29·50	28·45
Drilled each side	...	29·50

Mr. Boyd found in steel plates a loss of 2·15 per cent. due to drilling. Mr. Martell found no appreciable loss. The remarkable results obtained by Mr. Adamson, and already commented on, should be compared with the results here given.

Putting aside the experiments mentioned above, all other experiments show a considerable diminution of tenacity, in both iron and steel plates, due to punching. In Mr. Barnaby's earlier experiments the loss is exceptionally large, and it is possible that the sides of the plate were sheared in his experiments as well as the holes punched.

In M. Barba's experiments the proportionate loss of tenacity increases as the ratio of width of plate to diameter of hole increases. It may be presumed that this is due to the narrow strips yielding more in width than wide ones under the action of the punch. But this yielding could not occur with ordinary plates, and it is doubtful therefore if M. Barba's experiments afford a satisfactory measure of the loss of strength in punching wide plates. Mr. Kirk proceeded in a more satisfactory manner, punching a wide strip and then slotting it into strips suitable for experiment.

EXPERIMENTS ON TENACITY OF PUNCHED IRON PLATES.

Authority.	Thickness of Plate. Inches.	Width of Plate. Inches.	Number of Holes.	Diameter of Holes. Inches.	Tenacity.	Loss of Tenacity in per cent. of original strength.
Barnaby	0·625	2¼	—	0·875	16·4	
	0·375	2	—	0·75	17·45	
	0·375	2	—	0·75	16·66	
Stoney	0·375	3	1	0·75	15·4	15·6 } Mean 11·45
	0·375	4	2	0·875	19·24	10·2
	0·375	8	5	0·875	22·22	7·4
	0·375	8	5	0·875	21·97	12·6
Fletcher	—	—	—	—	20·15	5
Kirk	1·15	—	1	1·18	15·27*	} 18
	1·16	—	1	1·18	15·95*	
	1·17	—	1	1·22	16·81†	} 8
	1·16	—	1	1·22	17·02†	
Martell	0·8	—	—	—	—	20 to 23
Barba	—	1·24	1	0·66	16·81	5
	—	1·95	1	0·66	16·69	5½
	—	2·62	1	0·66	15·10	14
	—	3·35	1	0·66	14·72	17
	—	4·05	1	0·66	14·79	16
Maynard	—	—	—	—	—	19 ‡
Barnaby	0·54 to 0·75	2·8 to 3·3	2	1·00	19·0	11 §§
,,	,,	,,	,,	,,	17·7	17**
Parker	0·74	4·0	1	1·1 & 1·17	18·19	} 18·8
	0·74	4·0	1	1·1 & 1·32	18·93	

* Hole in die-block ⅛ in. larger in diameter than punch.

† Hole in die-block ¼ in. larger in diameter than punch.

‡ This is loss of punched as compared with drilled plate.

§§ Punched before shaping.

** Punched after shaping.

EXPERIMENTS ON TENACITY OF PUNCHED STEEL PLATES.

	Thickness of Plate. Inches.	Width of Plate. Inches.	Number of Holes.	Diameter of Holes. Inches.	Tenacity.	Loss of Tenacity in per cent. of original strength.
Barnaby	0·625	$2\frac{1}{4}$	1	0·875	14·5	
	0·375	2	1	0·75	18·54	
Wilson	0·375	2	1	0·75	22·08	23
Kirk	0·75	—	1	1·02	17·96*	33
	0·75	—	1	1·02	11·18*	
	0·75	—	1	1·05	23·21†	19
	0·75	—	1	1·05	20·40†	
	0·25	—	1	0·75	29·10	2
Boyd	—	—	—	—	—	51
	—	—	—	—	—	35
	—	—	—	—	21·15	31
Martell	0·8	—	—	—	—	22 to 33
Barba	0·27	1·24	1	0·66	26·98‡	
	0·27	1·95	1	0·66	26·11‡	
	0·27	2·65	1	0·66	24·39‡	
	0·27	3·35	1	0·66	23·09‡	
	0·27	4·05	1	0·66	23·88‡	
	0·27	4·75	1	0·66	23·31‡	
	0·27	1·24	1	0·66	31·95§	
	0·27	1·95	1	0·66	27·85§	
	0·27	2·65	1	0·66	25·25§	
	0·27	3·35	1	0·66	23·27§	
	0·27	4·05	1	0·66	23·57§	
	0·27	4·75	1	0·66	23·98§	
Barnaby (Open-hearth.)	0·6 to 0·7	2·9 to 3·3	2	0·875 to 1	23·7	13§§
,,	,,	,,	,,	,,	24·5	11**
Barnaby Converter	0·54 to 0·72	,,	2	0·875 to 1	21·7	21§§
,,	,,	,,	,,	,,	24·8	9**
Parker ††	0·687	4·0	Semi-hole at each edge	$1\frac{1}{8}$ & $1\frac{3}{16}$	22·92	17·8
	0·7	4·26	1	1·1 & 1·35	24·46	12·3
	0·7	4·26	1	1·0 & 1·35	21·04	24·5
	0·75	—	2	1·09 & 1·11	20·00	24·2
	0·75	—	2	1·08 & 1·24	18·69	28·7
	0·75	$8\frac{1}{4}$	2	1·09 & 1·19	20·50	30·0
	0·75	$8\frac{1}{4}$	2	1·09 & 1·22	19·08	
	0·25	—	2	0·69 & 0·74	29·48	8·1
	0·375	—	2	0·84 & 0·94	24·06	18·7
	0·468	—	2	0·97 & 1·11	21·38	26·2
	0·593	—	2	0·96 & 1·1	19·57	33·8
	0·75	—	?	$1\frac{1}{8}$	19·80	33·0

* Hole in die-block $\frac{1}{16}$ in. larger than punch. † Hole in die-block $\frac{1}{8}$ in. larger than punch. ‡ Cylindrical punching. Hole in die 0·76 in. diam.

§ Conical punching. Hole in die 0·82 in. diam. §§ Punched after shaping.

** Punched before shaping. †† The two dimensions in fifth column for these experiments are diameters of punch and hole in die-block.

These experiments cannot but be regarded as extremely discordant both for iron and steel, and they do not afford any adequate guide in predicting the probable loss of tenacity due to punching in different cases. But they show that that loss depends on the following circumstances:—(1) The material; (2) the diameter of the punch, or probably the ratio of diameter of punch to thickness of plates; (3) the width of metal round the hole, or probably the ratio of diameter of punch to pitch of riveting; (4) the ratio of diameter of punch to diameter of hole in die-block. If further experiments on this subject were made, it would seem most desirable to select extremely uniform qualities of iron and steel, so that a few experiments only should be necessary to obtain average values. Further, it would seem extremely desirable not to confine the experiments to strips with a single hole. Mr. Stoney's experiments, in which some test bars had five punched holes, rather seem to indicate that the proportionate loss is greatest in bars with only one hole.

In an experiment by Mr. Adamson the strength was increased by driving a pin into the hole, so as to prevent the metal round the hole from collapsing into an elliptical shape. As the holes in riveted joints are in this condition, it would be desirable to repeat this experiment.

In a single experiment by Mr. Sterne, it appeared that a spiral punch injured the material less than an ordinary punch to the extent of about 7 or 8 per cent.

Apparent Tenacity of Annealed and Rimered Plates.—All the experiments indicate a complete restoration of the original tenacity of the iron or steel, if the plate is annealed after punching, or if a narrow ring 0·04 in. to 0·08 in. wide is rimered out of the punched hole. These processes, by removing straining action or by removing the strained metal, bring back the bar to the condition of a bar with drilled holes. In a few experiments the material appears to gain a little in strength by annealing.

Apparent Shearing Resistance of Rivet Iron and Steel.—The true shearing resistance of the rivets cannot be ascertained from experiments on riveted joints, (1) because the uniform distribution

of the load over all the rivets cannot be ensured; (2) because the friction of the plates, which has the effect of increasing the apparent resistance to shearing, is an element uncertain in amount. Probably in the case of single-riveted joints the shearing resistance is not much affected by the friction; but for the present attention will be confined to special experiments on shearing.

	Ultimate Shearing Stress in tons per sq. in.	
Iron, single shear (12 bars)	24·15	Clark.
„ double shear (8 bars)	22·10	
„ „ „ „	22·62	Barnaby.
„ „ „ „	22·30	Rankine.*
„ $\frac{3}{4}$ in. rivets	23·05 to 25·57	Riley.
„ $\frac{5}{8}$ in. „	24·32 to 27·94	
„ mean value	25·0	
„ $\frac{5}{8}$ in. rivets	19·01	Greig and Eyth.
Steel	17 to 26	Parker.
Landore steel, $\frac{3}{4}$ in. rivets	31·67 to 33·69	Riley.
„ „ $\frac{5}{8}$ in. „	30·45 to 35·73	
„ „ mean value	32·3	
Brown's steel	22·18	Greig and Eyth.

* Deduced from Doyne's experiments.

Fairbairn's experiments show that a rivet is $6\frac{1}{2}$ per cent. weaker in a drilled than in a punched hole. By rounding the edge of the rivet hole the apparent shearing resistance is increased 12 per cent. Mr. Maynard found the rivets 4 per cent. weaker in drilled holes than in punched holes. But these results were obtained with riveted joints, and not by direct experiments on shearing. It must be remembered that there is a good deal of difficulty in determining the true diameter of a punched hole, and it is doubtful whether in these experiments the diameter was very accurately ascertained. Messrs. Greig and Eyth's experiments also indicate a greater resistance of the rivets in punched holes than in drilled holes.

If, as appears above, the apparent shearing resistance is less for double than for single shear, it is probably due to unequal distribution of the stress on the two rivet sections.

The shearing resistance of a bar, when sheared in circumstances which prevent friction, is usually less than the tenacity of the bar.

The following results, which are perhaps not all that could be found, show the decrease.

	Tenacity of Bar.		Shearing Resistance.		Ratio.
Harkort, Iron	26·4	......	16·5	......	0·62
Lavalley, Iron	25·4	......	20·2	......	0·79
Greig & Eyth, Iron	22·2	......	19·0	......	0·85
,, Steel......	28·8	......	22·1	......	0·77

In Wöhler's researches (in 1870) the shearing strength of iron was found to be $\frac{4}{5}$ of the tenacity. Later researches of Bauschinger confirm this result generally, but they show that for iron the ratio of the shearing resistance and tenacity depends on the direction of the stress relatively to the direction of rolling. The above ratio is valid only if the shear is in a plane perpendicular to the direction of rolling, and if the tension is applied parallel to the direction of rolling. The shearing resistance in a plane parallel to the direction of rolling is different from that in a plane perpendicular to that direction, and again differs according as the plane of shear is perpendicular or parallel to the breadth of the bar. In the former case the resistance is 18 to 20 per cent. greater than in a plane perpendicular to the fibres, or is equal to the tenacity. In the latter case it is only half as great as in a plane perpendicular to the fibres.*

Friction of Riveted Plates.—Mr. Clark made some experiments to determine the friction of plates riveted together, the pressure between the plates being due to the contraction of the rivet in cooling. These experiments gave for the friction, estimated per sq. in. of rivet section—

4·66, 3·72, 6·61, 7·88 tons.
Mean 5·72 tons.

Researches on friction and shearing made by Harkort, are given in Von Kaven's Collectaneen. The specimens were prepared in the form shown in the three Figs. 7, Plate 34. Specimens with the rivet in double shear (Fig. 7 A) were riveted hot. Specimens (Fig. 7 B) had a pin driven in, so that there should be no friction due to the contraction of the rivet. Lastly, specimens (Fig. 7 C) were riveted

* Muller. Beitrage zu der Vernietung eiserner Brücken.

2 E 2

hot with the rivet in single shear. Calling f_s the shearing resistance and f_f the friction between the plates for each rivet, then the tension required to break the joint would be,

$$\text{In case A.} \quad T_a = 2f_s + 2f_f$$
$$\text{,, B.} \quad T_b = 2f_s$$
$$\text{,, C.} \quad T_c = f_s + f_f$$
$$\text{Hence } f_f = \frac{T_a - T_b}{2} = T_c - \frac{T_b}{2}$$
$$f_s = \frac{T_a}{2} - f_f = \frac{T_b}{2} = T_c - f_f$$

Reducing results with $\frac{3}{4}$ in. rivets, the friction was found to amount to $4 \cdot 65$ tons per sq. in. of rivet area, and the shearing resistance of the rivets was $16 \cdot 5$ tons per sq. in. The absolute tenacity of the rivet iron was $26 \cdot 4$ tons per sq. in. Hence the shearing resistance was little more than $\frac{6}{10}$ of the tenacity. Lavelley made experiments for Gouin & Co., and found the shearing resistance of bars fixed in a steel fork to be $20 \cdot 2$ tons per sq. in., with iron having a tenacity of $25 \cdot 4$ tons per sq. in. Six experiments to determine the friction gave a mean of 10 tons per sq. in. of rivet area.

If this friction subsisted unimpaired till the fracture of the joint, the apparent shearing resistance would be increased by the whole amount here given. But as to produce this amount of friction the rivet must be strained beyond its elastic limit, the tension of the rivet probably relaxes a little in course of time. When the tension in the rivet does not exceed its elastic resistance, the friction may probably amount to 3 or $3\frac{1}{2}$ tons per sq. in. of rivet section. In the approach towards fracture even this amount of friction is probably almost or quite destroyed.

In some experiments by Mr. Parker it appeared that with lap joints there is a sensible separation of the plates at the edge of the overlap with one-eighth of the ultimate breaking weight. Mr. Parker infers that the plates slip and separate so much before fracture that, in these joints, the friction is destroyed before the breaking point is reached. The looseness of the rivets in the holes of some treble-riveted lap joints broken by tension, which are in Mr. Parker's possession, is very remarkable.

In Messrs. Greig and Eyth's experiments three strips were connected by a rivet so that the rivet was in double shear. The riveting was done by different machines, and then the rivet was broken by shearing. It appeared that the shearing resistance was highest with joints riveted by the machines which worked with the greatest pressure. With steel rivets $\frac{5}{8}$ in. diameter, in $\frac{11}{16}$ in. drilled holes, the pressure on the rivet when riveting and the shearing stress were as follows:—

	Pressure on Rivet in tons.		Shearing Resistance. Tons per sq. in.
Steam riveter	37	...	25·74
Stationary hydraulic riveter . . .	39	...	23·80
Portable hydraulic riveter . . .	20	...	22·78
Power riveter, light	31	...	22·50
" " heavy	52	...	23·76

If there is a real difference in the shearing resistance with different riveting pressures, it must be due to friction, or to some change in the strength of the material in the process of riveting. The difficulty in ascribing it to the former cause is this, that it is not probable that a red-hot rivet can retain the compression it receives from the riveting machine. It has hitherto generally been assumed that the clipping together of the plates which produces friction is due to the contraction of the rivet in cooling, and not to the pressure put upon it by the riveting machine.

Mr. Kirk has recently shown to the Reporter some joints cut through after riveting. These appear to show that in thick plates a tighter joint is obtained by continuing the riveting pressure for a sensible period, instead of removing it at once as in ordinary machine riveting. The point is not quite clearly made out, but it deserves further investigation. It does not seem at all impossible that thick plates may spring a little, while the rivet is still red hot, and it would be very objectionable if this were really the case.

Pressure on the bearing surface of the Rivet.—If P is the tension on a joint corresponding to one rivet, d the diameter of the rivet, and t the thickness of the plate, then

$$f_c = \frac{P}{td}$$

may be defined as the mean crushing pressure of the rivet on the plate. Putting f_s for the shearing resistance of the rivet, then, the rivets being in single shear,

$$f_c t d = f_s \frac{\pi}{4} d^2 = P$$

$$\frac{f_c}{f_s} = \cdot 785 \frac{d}{t},$$

or the crushing pressure is greater as the ratio of the rivet diameter to the thickness of plates is greater. This is sometimes given as the reason why the rivet diameter should not exceed $2\frac{1}{2}$ to 3 times the plate thickness. It is by some writers asserted, that if in any case f_c is more than 30 or 40 tons per sq. in. for iron joints, then the joint gives way with a very low apparent tenacity. During the application of the load the rivet-hole becomes oval, the metal of the plate is crushed and its tenacity diminished. The precise way in which the crushing affects the tenacity has not hitherto been indicated; but it is suggested above that it produces an unequal distribution of the stress similar to that induced by punching. There are no direct experiments on the crushing of iron and steel, which are of any value in determining the proper limits of crushing pressure for riveted joints. But it will be convenient to discuss here some results obtained with actual joints which have a bearing on this question.

To the Reporter it appears that there is no definite assignable value of f_c at which crushing action occurs. From the very irregular distribution of the pressure on the surface of the rivet it is probable that the maximum pressure of the rivet on the plate is much greater than its mean value f_c. Then for moderate values of f_c (25 to 30 tons per sq. in. for instance) the maximum pressure might be 50 or 60 tons, and under that pressure some crushing would almost certainly occur. Some experiments seem to show that while there is deterioration of the tenacity, even with ordinary values of f_c, that deterioration increases as f_c increases, and is very serious indeed if f_c amounts to 40 or 45 tons per sq. in., that is in the case of iron plates. For steel plates no experiments hitherto made show any great diminution of tenacity attributable to crushing action, although in some experiments the value of f_c reaches to 40 or 50 tons per sq. in.

Let Fig. 8, Plate 34, represent an ordinary joint. Then it

is known that the pressure of the rivet on the plate must be zero at the points o o, and increase to a maximum midway between them. Let P be the total stress on the joint corresponding to one rivet, and p be the intensity of the pressure at any point, between the rivet and plate, normal to the surfaces in contact. Let $t \frac{d}{2} \delta\alpha$ be an element of surface of the rivet subtended by the angle $\delta\alpha$ in the neighbourhood of that point. Then the whole pressure on that element of surface is $p\, t \frac{d}{2} \delta\alpha$, and its component in the direction of the load on the joint is $p\, t \frac{d}{2} \delta\alpha \cos \alpha$. Hence

$$P = t\, d \int_0^{\frac{\pi}{2}} p \cos \alpha\, \delta\alpha$$

Assume that* $p = p_{max} \cos \alpha$

then $$P = t\, d\, p_{max} \int_0^{\frac{\pi}{2}} \cos^2 \alpha\, \delta\alpha$$

$$= p_{max}\, t\, d\, \frac{\pi}{4}$$

But $$P = f_c\, t\, d$$

Hence $$p_{max} = 1 \cdot 27\, f_c\ ,$$

or the maximum crushing pressure is $1 \cdot 27$ times the mean crushing pressure. But it is also extremely probable that, in a plane at right angles to that thus far considered, there is also a variation of pressure The pressure at the points AA, Fig. 9, Plate 34, must be greater than that at BB, and if this variation were taken into consideration, we should get a much higher value for the ratio $\frac{p_{max}}{f_c}$.

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* If the rivet is assumed to remain cylindrical while crushing the plate (or the rivet-hole while the rivet is crushed), then the amount of crushing, measured in the direction of the movement of the rivet, will be constant for all parts of the rivet-hole, and the crushing measured normally to the rivet surface will vary as $\cos \alpha$. This gives the variation of normal pressure assumed above. When however the elastic limit has been passed, and actual crushing of the plate or rivet has occurred, the pressure will tend to become of uniform intensity.

In the following Table are enumerated all the experiments which seem to afford information about the limits of crushing pressure. Taking Fairbairn's experiments for instance, and comparing together

EXPERIMENTS SHOWING DEPENDENCE OF APPARENT TENACITY ON CRUSHING PRESSURE IN IRON PLATES.

	Form of Joint.	Crushing Pressure.	Apparent Tenacity of Joint.	Tenacity of original Plate.	Loss of Tenacity due to Crushing.
Fairbairn.	Lap, single riveted	37·4	18·7		
	,, ,, ,, ...	29·85	19·9		
	,, double ,, ...	34·95	23·3		
	,, ,, ,, ...	34·30	21·8		
	,, ,, ,, ...	26·10	26·1		
	,, ,, ,, ...	22·90	24·7		
	Butt, double, one cover	25·90	24·1		
	,, single, two covers	42·06	23·9		
	,, ,, ,, ,, ...	29·10	27·1		
Kirkaldy.	Lap, single riveted	26·13	21·1		
	,, double ,, ...	16·39	25·57		
	Butt, double riveted	33·34	19·63		
	,, ,, ,, ...	32·03	20·34		
	,, ,, ,, ...	28·19	20·08		
	,, ,, ,, ...	27·93	17·50		
Browne.	Lap, single riveted	41·81	12·95		
	,, ,, ,, ...	38·82	12·06		
	,, ,, ,, ...	37·93	11·74		
	Butt, single riveted	45·16	13·98		
	,, ,, ,, ...	42·07	12·97		
	,, ,, ,, ...	41·44	12·83		
Stoney.	Lap, single riveted, punched . .	29·56	14·24	22·00	7·76
	,, ,, ,, . .	24·84	14·67	18·54	3·87
	,, ,, ,, . .	22·08	16·77	21·43	4·66
	,, ,, ,, . .	21·10	16·00	21·43	5·43
	,, ,, ,, . .	19·50	20·48	21·43	0·95
	,, ,, ,, . .	18·80	19·76	21·43	1·67
	,, ,, ,, . .	17·31	18·22	24·00	5·78
	,, ,, drilled . .	28·75	20·90	22·00	1·10
	,, ,, ,, . .	26·35	15·57	22·00	6·43
	,, ,, ,, . .	24·39	18·52	21·43	2·91
	,, ,, ,, . .	21·59	16·37	21·43	5·06
	,, ,, ,, . .	21·22	21·22	21·43	0·21
	,, ,, ,, . .	20·60	21 59	21·43	Gain.
	,, ,, ,, . .	20·50	21·54	21·43	Gain.

Each set of experiments in this Table is arranged in the order of the crushing pressures.

those which are bracketed (because made of one form of joint), there seems to be a tolerably regular increase of apparent tenacity as the crushing pressure diminishes. The diminution of tenacity is sensible in lap joints where the crushing pressure exceeds 30 tons. The general bearing of Mr. Stoney's experiments is slightly in the same direction. In Mr. Browne's experiments, where the crushing pressure reaches 40 tons, the diminution of tenacity is very great, though the Reporter feels some doubt as to whether this is entirely due to crushing action.

Pin Connections.—In the case of the pin connections of suspension links, it has been found that to obtain a strength at the joint equal to that in the body of the bar, the pin diameter d must not be less than $0 \cdot 8$ of the width b of the body of the bar, and the section of the bar through the pin hole must not be less than $1 \cdot 5$ times the section of the body of the bar. From the former proportion we may deduce the result that the ratio of the crushing pressure and tenacity is—

$$\frac{f_c}{f_t} = \frac{b}{d} = \frac{1}{0 \cdot 8} = 1 \cdot 25.$$

From the latter proportion it may be inferred that the unequal distribution of stress round the hole makes the apparent tenacity of the metal surrounding it less than the tenacity of the bar, in the ratio $0 \cdot 666$, giving a loss of tenacity of 33 per cent. These results, though not strictly applicable to riveted joints, are interesting for comparison with the crushing pressure and apparent tenacity observed in experiments on riveted joints.

So long as attention is confined to the experiments on iron lap-joints, a tolerably consistent decrease of tenacity * with increase of crushing pressure is observed. With the experiments on iron butt-joints however this is no longer the case. There are instances in which a high crushing pressure has apparently much reduced the

* By decrease of tenacity is here meant simply reduction of the ratio $\frac{\text{Breaking load}}{\text{Area of metal in joint}}$, whether that reduction is due to alteration of quality of material, or to reduction of average strength in consequence of the stress being unequally distributed.

tenacity, and other instances where the tenacity seems to have been unaffected. With steel joints also, even with very high crushing pressures, no regular effect on the tenacity is traceable. It seems possible to the Reporter that the explanation of these anomalies may be found in the variation of the relative hardness of the rivets and plate. If the rivet is sensibly harder than the plate, the plate will suffer; but if the rivet is sensibly softer than the plate, the rivet will suffer. With iron plates, sometimes the rivet and sometimes the plate is the harder. With steel, the rivet appears to be generally softer than the plate. It must be borne in mind that this suggestion is only offered as a conjectural explanation of anomalies which, unless they are due to errors in the experiments, are extremely puzzling.

Diameter of Rivets.—In a joint there are three variable quantities to be determined—the thickness of the plate t, the pitch p, and the diameter of the rivet d. The three limiting stresses—tearing, crushing, and shearing—furnish three conditions for fixing these quantities. In practice the diameter of the rivet is usually fixed empirically, and there is a redundant condition to satisfy. Hence it is usually necessary to make one of the stresses less than the limiting stress. But this does not seem a very satisfactory proceeding.

Putting f_c for the crushing and f_s for the shearing stress, and equating the shearing and crushing resistance, we get for rivets in single shear—

$$\frac{\pi}{4} d^2 f_s = t d f_c$$

$$\frac{d}{t} = 1 \cdot 27 \frac{f_c}{f_s}.$$

Similarly for rivets in double shear—

$$\frac{d}{t} = 0 \cdot 635 \frac{f_c}{f}.$$

If therefore f_c and f_s are fixed theoretically, the ratio $\frac{d}{t}$ is also determined. Thus, for example, in the case of iron, for rivets in

single shear, taking $f_c = 30$ tons, $f_s = 20$ tons, $\frac{d}{t} = 1 \cdot 9$. Taking $f_c = 40$ and $f_s = 20$, then, for rivets in double shear, $\frac{d}{t} = 1 \cdot 27$.

It would seem desirable to enquire how far the existing empirical practice as to the diameter of rivets is based on practical advantage. Ordinarily the diameter chosen for the rivet is made to depend on the thickness of the plates, independently of any consideration of the form of joint. But if the crushing stress is greater, as appears from the experiments, for joints with double covers than for joints with single covers, and greater for butt than for lap joints, and if the shearing stress is different for single and multiple riveting, then to adopt a diameter of rivet depending only on the thickness of the plate does not at all conform to theoretical requirements.

It may be convenient to give here some of the rules which have been proposed for the diameter of the rivet in single shear:—

Browne	$d = 2t$ (with double covers $1\frac{1}{4}t$)	(1)
Fairbairn	$d = 2t$ for plates less than $\frac{3}{8}$ in.	(2)
"	$d = 1\frac{1}{2}t$ for plates greater than $\frac{3}{8}$ in.	(3)
Lemaitre	$d = 1 \cdot 5t + 0 \cdot 16$	(4)
Antoine (*a*)	$d = 1 \cdot 1 \sqrt{t}$	(5)
Pohlig (*b*)	$d = 2t$ for boiler riveting	(6)
"	$d = 3t$ for extra strong riveting	(7)
Redtenbacher (*c*)	$d = 1 \cdot 5t$ to $2t$	(8)
Unwin (*d*)	$d = \frac{3}{4}t + \frac{5}{16}$ to $\frac{7}{8}t + \frac{3}{8}$	(9)
,, (*e*)	$d = 1 \cdot 2 \sqrt{t}$	(10)

(*a*) Naval Science, vol. i., 1872. (*b*) Maschinentheile, 1877.
(*c*) Construction des Machines, 1874. (*d*) Wrought-Iron Bridges, 1869.
(*e*) Machine Design, 1877.

The following Table contains some data of the sizes of rivets used in practice, and the corresponding sizes given by some of these rules:—

DIAMETER OF RIVETS FOR DIFFERENT THICKNESSES OF PLATES.

Thickness of Plate. Inches.	Diameter of Rivets, in Inches.											
	Lloyd's Rules.	Liverpool Rules.	English Dockyards.	French Bureau Veritas.	Browne Eq. 1.	Fairbairn (2) & (3).	Lemaitre (4).	Antoine (5).	Unwin (10).	Wilson.	Havrez.	Hall.
5/16	5/8	5/8	1/2	—	5/8	5/8	5/8	5/8	11/16	5/8	11/16	5/8
3/8	5/8	5/8	5/8	5/8	3/4	3/4	23/32	11/16	3/4	11/16	3/4	11/16
7/16	5/8	3/4	3/4	5/8	7/8	21/32	13/16	3/4	13/16	3/4	13/16	13/16
1/2	3/4	13/16	3/4	—	1	3/4	15/16	3/4	7/8	3/4	7/8	15/16
9/16	3/4	13/16	7/8	3/4	1 1/8	27/32	1	13/16	7/8	7/8	1	1
5/8	3/4	7/8	7/8	—	1 1/4	15/16	1 1/8	7/8	15/16	7/8	1	1 1/16
11/16	7/8	7/8	7/8	13/16	—	1 1/32	1 3/16	15/16	1	7/8	—	—
3/4	7/8	15/16	1	7/8	—	1 1/8	1 1/4	15/16	1 1/16	1	—	—
13/16	7/8	1	1	—	—	1 7/32	1 3/8	1	1 3/32	1	—	—
7/8	1	1 1/8	1 1/8	1	—	—	—	1	1 1/8	1	—	—
15/16	1	1 3/16	1 1/8	—	—	—	—	1 1/16	1 3/16	1 1/8	—	—
1	1	1 1/4	1 1/8	1 1/16	—	—	—	1 1/8	1 1/4	1 1/8	—	—

Overlap, and distance from Rivet to edge of Plate.—It is ordinarily stated that holes cannot safely be punched nearer than one diameter from the edge of the plate; and this amount of overlap appears in most cases to afford ample strength to resist the tendency of the rivet to burst through the edge of the plate.

The precise distance to give security against the bursting of the edge of the plate cannot be determined theoretically, the condition of stress and loading being both complex. Most treatises on riveting assume that the rivet tends to shear the plate at the lines *a a*, *b b*, Fig. 6, Plate 34. No experiment is known to the Reporter in which a plate has thus given way. In some experiments the fracture takes place along the lines *a b*, *c d*, *e f*, Fig. 6*a*, simultaneously. This form of fracture can however only occur in joints with a single rivet; and the breaking in this way perhaps indicates that, at the end rivet of a row, some extra metal should be allowed between the rivet and the side of the plate, or that the distance to the side of the plate should a little exceed the half pitch.

Except at the ends of the joint, the metal in front of each rivet is in the position of a bar encastré at each end, and transversely loaded. Treating the load as concentrated at the centre, and putting l = distance from centre of rivet to edge of plate, f = the greatest stress due to bending, we get for the relation between the shearing strength of the rivet and the resistance of the plate to cross-breaking*—

$$\frac{\pi}{4} d^2 f_s = \frac{1}{3} \frac{(2l - d)^2}{d} tf,$$

which gives

$$l = \sqrt{\frac{3\pi}{16} \frac{d^3}{t} \frac{f_s}{f}} + \frac{d}{2}.$$

If we put f = the ordinary tearing resistance of the iron, we get for l a value a little less than that usual in practice. But it would probably be worth while to make a few direct experiments to determine the value of the constant c in a formula of the form

$$l = c \sqrt{\frac{d^3}{t}} + \frac{d}{2}$$

* The greatest bending moment for a beam encastré at the ends must lie between $\frac{1}{12}$ Td, and $\frac{3}{16}$ Td, where T is the total load on a rivet. Taking it at $\frac{1}{8}$ Td, and equating this to the moment of resistance of the section in front of the rivet, which is $\frac{1}{6}\, tf \left(l - \frac{d}{2}\right)^2$, we get the formula above.

which would ensure the width of overlap being sufficient to prevent cross-breaking. In such experiments it might probably be necessary to prevent the lateral spreading of the two parts into which the plate under the rivet divides, by clips embracing the joint tightly. This would make a joint with one rivet approximate to the condition of a portion of a longer joint.

(IV.) EXPERIMENTS ON RIVETED JOINTS.

Hitherto the discussion has been chiefly confined to data best determined by special experiments. It remains to discuss the data which can only be ascertained by experiments on different forms of riveted joints. What it is chiefly necessary to determine by such experiments is the relation of the tearing strength of the iron in the joint to the tenacity of the original plate, and to the shearing stress which the rivets will carry before giving way. It is by means of these relations that the pitch and strength of the joint have to be determined.

We may call the ratio of the tension on the joint to the tearing section of the plate at the place of fracture the *Apparent Tenacity* of the joint. Then that apparent tenacity is rendered less than the original tenacity of the iron—(1) by any injury done in drilling or punching; (2) by any irregularity of stress due to the way in which the rivets load or crush the plate; (3) by any irregularity of distribution of stress due to the bending of the joint as a whole under the action of the load. The apparent shearing resistance will be less than that determined by the special experiments above—(1) if the load is not equally divided amongst the rivets; (2) if any crushing of the rivet by the plate causes an increase of stress on part of the rivet section.

Let f_s be the apparent shearing resistance, and Ω_s the shearing section of the rivets in any given joint or length of joint. Let f_t be the apparent tearing resistance, and Ω_t the section of the plate through the rivet holes where the section is smallest. Then the strongest joint will be that for which

$$f_t \, \Omega_t = f_s \, \Omega_s.$$

If the diameter of the rivets is determined, either empirically or to secure a given limit of crushing pressure, then the equation just given determines the pitch of the riveting. The object of experiments on complete riveted joints is to determine the values of f_t and f_s for different kinds of joints. To determine these stresses two experiments are required, one on a joint which has given way by tearing, and one on a joint which has given way by shearing. One joint should be designed with an excess of tearing area, the other with an excess of shearing area, but in other respects they should be identical. Unfortunately this has seldom been done in the experiments which have been made.

I. *Single-riveted Lap Joints of Iron.*—The following two Tables contain all the reliable experiments which have been found on single-riveted lap joints of iron, broken by tearing or shearing. From these Tables all experiments have been excluded in which the crushing pressure of the rivet on the plate was so great as obviously or probably to have affected in any considerable degree the apparent tenacity of the joint.*

* In all these Tables the stresses corresponding to the actual mode of fracture of the joint are printed in heavy type. Thus in this Table the joints all gave way by tearing, and the tensile stress is therefore given in heavy type. The crushing and shearing stresses, given for comparison, are therefore lower than the stresses at which the joint would have given way by crushing or shearing. Where there are heavy figures in *two* columns, it implies that the joint gave way by both modes of fracture simultaneously.

Single-Riveted Lap Joints Broken by Tearing.—Iron. (See Foot-note, p. 339.)

Mode of Riveting.	Holes made by.	Tenacity of Iron. Tons per sq. in.	Stress at Moment of Fracture in Tons per sq. in.			Efficiency of Joint. Per cent.	Remarks and Source of Experiments.
			Tensile.	Shearing.	Crushing.		
Hand . . .	Punch .	25·77	16·37	18·33	32·74	46	Sir W. Fairbairn—Rivet heads broke off.
,, . . .	,, .	,,	16·35	18·31	32·70	46	,, Rivet heads cracked.
Machine . .	,, .	,,	19·95	14·90	26·63	44	,,
(?) . . .	,, .	(?)	20·15	14·13	25·89	(?)	Hendry.
,, . . .	,, .	,,	15·31	16·23	25·45	,,	,,
,, . . .	,, .	,,	15·65	15·38	21·43	,,	,,
,, . . .	,, .	,,	20·74	13·19	24·12	,,	,,
Steam . . .	,, .	21·60	21·11	15·59	26·13	54	Kirkaldy.
Hand . . .	,, .	18·54	14·67	16·21	24·84	50	B. B. Stoney.
,, . . .	,, .	22·00	14·24	19·79	29·56	44	,,
,, . . .	,, .	21·43	20·48	10·89	19·50	47	,,
,, . . .	,, .	,,	19·76	10·51	18·80	45	,,
,, . . .	,, .	,,	16·00	12·12	21·10	45	,,
,, . . .	,, .	,,	16·77	12·69	22·08	47	,,
,, . . .	,, .	24·00	18·22	10·49	17·31	37	,,
,, . . .	Drill .	22·00	15·57	16·97	26·35	45	,,
,, . . .	,, .	,,	20·90	18·30	28·75	55	,,
,, . . .	,, .	21·43	21·59	12·12	20·60	50	,,
,, . . .	,, .	,,	16·37	12·41	21·59	44	,,
,, . . .	,, .	,,	21·54	11·46	20·50	50	,,
,, . . .	,, .	,,	18·52	14·01	24·39	50	,,
,, . . .	,, .	24·00	21·22	12·83	21·22	44	,,
(?) . . .	Punch .	26·70	22·30	25·60	40·23	—	Master Mechanics' Association (Mean of 3).
Steam . . .	Drill . .	22·25	19·48	18·44	26·56	50·4	Greig and Eyth.
,, . . .	Punch . .	,,	16·80	14·89	21·38	40·6	,, ,,
Hand . . .	Drill . .	,,	17·96	17·00	24·48	46·5	,, ,,
Steam . . .	,, . .	,,	19·63	18·61	26·77	50·8	,, ,,
Hydraulic . .	,, . .	,,	20·43	19·35	27·86	52·9	,, ,,
Steam . . .	Drill . .	,,	21·29	17·31	29·59	57·6	,, ,,

Single-riveted Lap Joints, broken by Shearing.—Iron. (See Foot-note, p. 339.)

Mode of Riveting.	Holes made by.	Tenacity of Iron. Tons per sq. in.	Stress at Moment of Fracture in Tons per sq. in.			Efficiency of Joint. Per cent.	Remarks and Source of Experiments.
			Tensile.	Shearing.	Crushing.		
(?) . . .	Punch .	25·77	17·99	22·40	30·00	44	Sir W. Fairbairn.
Hand . . .	Punch .	22·00	11·97	17·78	27·94	38	B. B. Stoney.
,, . . .	,, . .	22·00	14·75	19·90	32·60	46	,,
,, . . .	Drill . .	22·00	15·10	18·63	29·63	46	,,
,, . . .	,, . .	,,	17·75	17·90	28·84	50	,,
,, . . .	,, . .	,,	20·90	18·30	28·75	55	,,
Machine . .	Punch .	—	—	19·53	—	—	Sir W. Fairbairn.
Hand . . .	Punch .	—	—	20·51	—	—	,,
Machine . .	Drill . .	—	—	18·51	—	—	,,
Hand . . .	Drill . .	—	—	20·34	—	—	,,
Hand . . .	Punch .	—	—	21·20	—	—	,, Countersunk.
Machine . .	Drill . .	—	—	19·58	—	—	,, ,,
(?) . . .	Drill . .	26·70	20·8	23·8	37·35	—	Master Mechanics' Association (mean of 3).
Steam . . .	Drill . .	22·25	19·48	18·44	26·56	50·4	Greig and Eyth.
,, . . .	,, . .	,,	19·63	18·61	26·77	50·8	,, ,,
Hydraulic . .	Drill . .	,,	20·43	19·35	27·86	52·9	,, ,,
Steam . . .	Drill . .	,,	21·29	17·31	29·59	57·6	,, ,,

Taking the different sets of experiments, the following average values are obtained:—

Authority.	Mode of Preparing Holes.	Mean Apparent Tenacity of Joint. Tons per sq. in.	Ratio of Mean Apparent Tenacity to Tenacity of Original Plate. Per cent.	Mean Shearing Resistance of Rivets. Tons per sq. in.	Ratio of Tenacity of Plate to Shearing Resistance of Rivets. Per cent.
Fairbairn . . .	Punched .	17·55	68·11	22·40	78·3
Hendry . . .	,, .	17·96	—	—	—
Stoney	,, .	17·16	79·97	18·84	91·0
,, ...	Drilled .	19·39	88·31	18·27	106·1
Fairbairn . . .	Punched .	—	—	20·41	—
,, . . .	Drilled .	—	—	19·47	—
Master Mechanics' Association . .	Punched .	22·30	83·52	—	—
	Drilled .	—	—	20·80	—
Greig and Eyth .	Punched .	16·80	75·50	—	—
	Drilled .	19·75	88·70	18·43	107·1
Mean Result . .	Punched .	18·35	76·77	20·55	84·6
,, . .	Drilled .	19·57	88·50	19·24	106·6

The mean stresses here found are not very discordant; but an examination of the detailed experiments, in which there are considerable variations, tends to lessen the value of the average results.

It appears that the apparent tenacity of the joint is at least 20 per cent. less than that of the original plate with punched joints, and 12 per cent. less with drilled joints. The shearing strength is 6 per cent. greater in punched holes than in drilled holes. But this result must be received with hesitation, because it is doubtful if the true diameter of the rivet has ever been determined in experiments with punched joints. With punched joints the tenacity of the plates is only 85 per cent. of the shearing resistance of the rivets, per sq. in.; but with drilled joints the plates are stronger per unit of area than the rivets in the ratio of 1·07 : 1.

In regard to the difference of apparent tenacity in drilled and punched joints, it is hardly so great as experiments on the effect of punching and drilling indicate. But the loss of tenacity of 12 per cent. in drilled joints seems to show that there is a considerable loss

of strength, ascribable to bending and other causes, which affects both kinds of joint equally.

The reduction of tenacity in lap joints is commonly ascribed to the bending of the specimen when tested. It should be noticed however that the bending occurs chiefly at the points *a a*, Fig. 10, Plate 34, whilst the actual fracture occurs in the plane *b b*. More probably the reduction of strength is due to the way in which the pressure of the rivet is distributed on the plate. The probable distribution is roughly indicated by the relative lengths of the arrows in Fig. 10. It will be seen that the bending and crushing of the plate tend to bring the resultant tension towards the inside edges of the sections of fracture, and thus virtually to reduce the strength. The wider the lap and the more rows of rivets there are, the less this action is likely to be, and the more nearly the tenacity of the joint will approach that of the plate. (See Appendix I.)

II. *Single-riveted Butt Joints of Iron.*—The experiments on these are less accordant than those on lap joints, and they are far less complete. The crushing pressures in Sir W. Fairbairn's experiments are higher than those in Mr. Browne's experiments. But while the former give an average tenacity of 22·38 tons, the latter give only 13·17 tons. No satisfactory general conclusions can be drawn from these experiments. The mean shearing resistance in two experiments is 20 tons, which is about the same as for lap joints.

The experiments are comprised in the Table on the following page.

SINGLE-RIVETED BUTT JOINTS BROKEN BY TEARING.—IRON.

Mode of Riveting.	Holes made by.	Tenacity of Iron. Tons per sq. in.	Stress at Moment of Fracture in Tons per sq. in.			Efficiency of Joint. Per cent.	Remarks and Source of Experiments.
			Tensile.	Shearing.	Crushing.		
(?)	Punch .	25·77	16·62	22·06	29·47	41	Sir W. Fairbairn. Single cover. Countersunk rivets.
(?)	,, .	,,	26·13	17·34	46·25		,, double covers.
(?)	,, .	,,	21·70	15·08	38·50	60	,, ,,
(?)	,, .	,,	25·09	16·66	44·51		,, ,,
Hand	Punch .	Best Staffordshire Boiler Plate, Tenacity 20–22 Tons per sq. in.	12·86	8·73	41·67	Joints not prepared with view to efficiency.	Walter R. Browne. Double cover.
,, ...	,, .		13·19	9·23	42·73		,, ,,
,, ...	,, .		12·85	8·49	41·82		,, ,,
,, ...	,, .		12·66	8·05	41·01		,, ,,
,, ...	,, .		13·15	8·93	42·61		,, ,,
,, ...	,, .		12·69	8·26	40·70		,, ,,
,, ...	,, .		13·39	8·44	42·94		,, ,,
,, ...	,, .		14·29	9·70	46·30		,, ,,
,, ...	,, .		14·25	9·39	46·25		,, ,,
Steam	Drill .	22·25	18·42	17·44	25·11	46·6	Greig and Eyth. Single cover.
,, ...	,, .	,,	24·24	11·48	33·83	62·7	,, Double covers.

SINGLE-RIVETED BUTT JOINTS BROKEN BY SHEARING.—IRON.

Mode of Riveting.	Holes made by.	Tenacity of Iron. Tons per sq. in.	Tensile.	Shearing.	Crushing.	Efficiency of Joint. Per cent.	Remarks and Source of Experiments.
(?)	Punch .	25·77	16·62	22·06	29·47	41	Sir W. Fairbairn. Single cover.
Steam	,, .	24·08	13·87	17·92	20·06	34	Kirkaldy. Single cover.

III. *Double-riveted Lap and Butt Joints of Iron.*—These experiments (as given in the two following Tables) are tolerably

Double-Riveted Lap Joints, broken by Tearing.—Iron.

Mode of Riveting.	Holes made by.	Tenacity of Iron. Tons per sq. in.	Stress at Moment of Fracture in Tons per sq. in.			Efficiency of Joint. Per cent.	Remarks and Source of Experiments.
			Tensile.	Shearing.	Crushing.		
Hand . .	Punch .	25·77	22·97	17·15	30·62	58	Sir W. Fairbairn.
,, . .	,, .	,,	23·74	17·73	31·69		
,, . .	,, .	,,	20·38	18·00	27·17		
,, . .	,, .	,,	23·24	20·51	31·02		
,, . .	,, .	,,	26·05	19·45	26·05	60	,,
,, . .	,, .	,,	24·41	17·00	22·78		
Steam . . .	Punch .	21·98	25·57	10·05	16·39	62·8	Kirkaldy. Between outside rivet and side of plate only 0·3 in. of metal.
Machine . .	Punch .	18·7	16·28	16·60	25·17	60	Easton and Anderson. Plates not annealed.
,, . .	,, .	,,	15·48	15·71	23·84		
,, . .	,, .	,,	17·31	17·65	26·77		
Steam . .	Drill .	22·25	20·44	17·68	25·46	62·9	Greig and Eyth.
Steam . .	Drill .	,,	21·90	8·94	15·22	59·2	,, ,,
Hydraulic . .	Punch .	19·55	10·91	11·60	9·83	35·9	R. V. J. Knight. Experiments made by Kirkaldy. Plates 1 in. thick. These results are kept separate from the preceding, as they show a very great reduction of tenacity in the joint.
,, . .	,, .	,,	10·55	11·23	9·53	34·7	
,, . .	,, .	23·2	12·79	10·20	9·60	33·1	
,, . .	,, .	,,	13·22	10·53	9·92	34·2	
(?) .	,, .	21·5	12·18	15·10	13·54	42·0	R. V. J. Knight, $\frac{7}{8}$ in. plates.
(?) .	,, .	,,	12·83	15·54	13·94	43·2	

DOUBLE RIVETED BUTT JOINTS, BROKEN BY TEARING.—IRON.

Mode of Riveting.	Holes made by.	Tenacity of Iron. Tons per sq. in.	Stress at Moment of Fracture in Tons per sq. in.			Efficiency of Joint. Per cent.	Remarks and Source of Experiments.
			Tensile.	Shearing.	Crushing.		
	Punch .	25·77	23·74	18·92	25·33	60	Sir W. Fairbairn. Single cover.
	,, .	,,	24·42	17·45	26·05		
	,, .	,,	24·07	19·18	25·68		
	,, .	,,	19·41	10·55	20·69	67	,, Double covers.
	,, .	,,	23·46	11·09	29·66		
Machine . .	,, .	21·5	16·12	16·43	29·48	60	Easton and Anderson. Double covers. Outside rivets only 0·54 and 0·65 in. from side of plate. Half net section between rivet holes would have required 0·9 inch.
	,, .	...	23·1	19·26	37·84	...	Martell. Single cover.
	,, .	...	16·8	21·00	27·52	...	,, ,,
Hand . . .	,, .	20·49	17·50	11·73	27·93	63·5	Kirkaldy. Double covers.
,, . . .	,, .	18·81	19·63	9·38	33·34	72·6	,, ,,
,, . . .	,, .	25·28	20·08	12·34	28·19	57·3	,, ,,
,, . . .	,, .	25·16	20·34	14·00	32·03	59·3	,, ,,
Steam . . .	Drill . .	22·25	18·07	15·63	22·50	55·6	Greig and Eyth. Single cover.
,, . . .	,, .	,,	20·65	8·92	25·72	63·5	,, ,, Double covers.
Hydraulic . .	Punch .	19·35	17·53	6·90	13·0	53·8	R. V. J. Knight. Double covers, 1 in. plates.
,, . .	,, .	,,	17·51	6·90	13·0	53·7	

numerous, so far as the tearing resistance of plates with punched holes is concerned; but there are no experiments with drilled holes, and none in which the joint gave way by shearing.

The exceptionally low tenacity found in Mr. Knight's experiments is difficult to understand. The joints were made with rather thick plates, and Mr. Knight in a letter to the Reporter explains the reduction of strength by the bending of the joint during testing. But these results must nevertheless be regarded as exceptional, because not only is the reduction of strength far greater than in any other experiments in this Table, but no such reduction of strength appears to occur with steel joints, which are even more deformed in testing than iron joints. A further discussion of this point, and some additional experiments, are given in Appendix I.

The following Table gives the mean results for lap and butt joints double-riveted:—

Description.	Authority.	Apparent Tenacity of Joint. Tons per sq. in.	Ratio of Apparent Tenacity to Tenacity of Original Plate. Per cent.
Lap Joints.			
Single Shear, Punched .	Fairbairn . . .	23·50	91·2
,, ,, ,, .	Kirkaldy . . .	25·57	116·2
,, ,, ,, .	Easton & Anderson .	16·35	87·4
,, ,, Drilled .	Greig and Eyth . .	21·17	95·0
,, ,, Punched .	Knight	12·08	56·4
Butt Joints.			
Single Cover, Punched .	Fairbairn . . .	24·07	93·4
,, ,, ,, .	Martell	19·95	—
Double Cover, ,, .	Fairbairn . . .	21·44	83·2
,, ,, ,, .	Kirkaldy	19·39	86·4
Single Cover, Drilled . .	Greig and Eyth. .	18·07	81·2
Double Cover, Drilled .	,, ,,	20·65	92·8
Double Cover, Punched .	Knight	17·52	90·0

Unfortunately the original strength of the plate in Fairbairn's experiments is not very certainly determined. Mr. Martell does not give the original strength of the iron, and his two results are

very discordant. The experiments on this form of joint are therefore incomplete and unsatisfactory.

IV. *Resistance to Shearing of Iron and Steel Rivets in Steel Plates.*—As the form of the joint does not appear sensibly to affect the resistance to shearing of the rivets, the whole of the shearing results for steel plates are grouped in the following Tables :—

LAP JOINTS BROKEN BY SHEARING.—STEEL PLATES AND STEEL RIVETS.

Mode of Riveting.	Holes made by.	Tenacity of Steel. Tons per sq. in.	Stress at Moment of Fracture in Tons per sq. in.			Efficiency of Joint. Per cent.	Remarks and Source of Experiments.
			Tensile.	Shearing.	Crushing.		
Single . . .	Drill .	36·22	24·93	25·53	36·04	41	Henry Sharp.
,, . . .	Punch .	,,	26·25	25·87	37·58	42	,,
Double . . .	Drill .	36·22	42·33	25·95	36·69	70	,,
,, . . .	Punch .	,,	37·00	21·88	31·74	60	,,
,, . . .	Drill .	,,	23·68	24·26	34·26	39	,,
,, . . .	Punch .	28·93	24·1	23·96	37·65	61	B. Martell.
,, . . .	Drill .	,,	24·5	24·37	38·27	61	,,
,, . . .	Punch .	36·20	33·90	25·51	37·93	63	Kirkaldy. (1)
,, . . .	,, .	,,	27·81	24·60	35·86	56	,,
,, . . .	,, .	25·9	17·6	19·85	33·98	..	Easton & Anderson.
Treble . . .	Drill .	28·93	27·4	30·00	31·47	73	B. Martell.
,, . . .	,, .	,,	26·7	29·25	30·66	72	,,
,, . . .	,, .	,,	19·7	25·43	28·26	55	,,
,, . . .	,, .	,,	22·2	24·75	25·92	60	,,
,, . . .	,, .	,,	21·9	18·60	21·92	57	,
,, . . .	,, .	,,	22·0	30·28	32·66	62	,
,, . . .	,, .	,,	23·3	32·04	34·59	66	,,
Single, Steam .	Drill .	25·83	27·40	23·95	34·50	56·6	Greig & Eyth.
,, ,, .	Punch .	,,	28·80	25·46	36·67	59·6	,,
,, ,, .	,, .	,,	38·87	25·52	36·76	60·2	,,
Single, Hand .	Drill .	,,	22·16	20·98	30·22	49·4	,,
Single, Steam .	,, .	,,	26·22	24·83	35·76	58·5	,,
Single, Hydraulic	,, .	,,	84·35	23·05	33·21	54·4	,,
Double . . .	Drill .	,,	26·14	22·61	32·56	70·0	,,
Treble chain .	Drill .	31·7	32·30	25·1	36·01	79	Parker. ¼″ Plate. (2)
,, ,, .	,, .	29·1	29·89	25·5	25·10	73	,, ½″ ,,
,, ,, .	,, .	30·4	25·89	23·9	23·14	62	,, ¾″ ,,
,, ,, .	,, .	27·5	26·07	24·1	20·54	67	,, 1″ ,,
Treble zigzag .	,, .	27·4	19·74	19·4	19·63	54	,, ⅞″ ,, (3)
,, ,, .	,, .	27·3	21·41	20·6	21·25	54	,, ⅞″ ,,
Quadruple zigzag	,, .	27·4	25·91	19·2	19·51	71	,, ⅞″ ,,

(1) Experiments made for the Bolton Iron and Steel Company.

(2) This and the three following joints were made by Messrs. Denny, and tested by Mr. Kirkaldy.

(3) This and the two following joints were tested by Mr. Kirkaldy for the Steel Company of Scotland.

BUTT JOINTS BROKEN BY SHEARING.—STEEL PLATES AND STEEL RIVETS.

Mode of Riveting.	Holes made by.	Tenacity of Steel. Tons per sq. in.	Stress at Moment of Fracture in Tons per sq. in.			Efficiency of Joint. Per cent.	Remarks and Source of Experiments.
			Tensile.	Shearing.	Crushing.		
Single-riveted .	Drill . .	36·22	23·68	**24·26**	34·26	39	Henry Sharp. One cover.
,,	Punch . .	,,	24·53	**24·17**	35·12	40	,, ,,
,,	Drill . .	,,	36·62	**18·75**	52·94	60	,, Two covers.
Double-riveted	,, . .	36·22	**39·25**	**24·05**	34·02	64	,, One cover.
,,	Punch . .	28·93	21·60	**26·12**	35·39	57	B. Martell. One cover.
,,	,, . .	,,	23·30	**31·95**	37·65	61	,, ,,
Single . . .	Drill . .	25·83	25·03	**23·69**	34·11	55·8	Greig and Eyth. One cover.
Double . . .	,, . .	,,	25·66	**22·72**	31·96	68·0	,, ,, ,,
Double, Two Covers . .	Drill . .	28·2	27·23	**19·8**	27·10	·72	W. Parker. $\frac{7}{8}''$ plate. Joint made by Messrs. Denny; tested by Mr. Kirkaldy.

JOINTS BROKEN BY SHEARING.—STEEL PLATES AND IRON RIVETS.

Mode of Riveting.	Holes made by.	Tenacity of Steel. Tons per sq. in.	Stress at Moment of Fracture in Tons per sq. in.			Efficiency of Joint. Per cent.	Remarks and Source of Experiments.
			Tensile.	Shearing.	Crushing.		
Double-riveted Lap .	Punch . .	28·93	19·20	**19·05**	30·00	49	B. Martell.
Double-riveted Butt, one cover . . .	,, . .	,,	16·70	**23·39**	27·54	44	,,
Double-riveted Lap .	,, . .	27·4	25·27	**19·81**	25·27	60·6	R. V. J. Knight.
,, ,, .	,, . .	27·4	24·71	**19·36**	24·71		
,, ,, .	,, . .	26·3	24·86	**19·54**	24·86		Plates annealed.
Treble-riveted Lap .	Drill . .	28·8	31·92	**17·4**	23·93	77	(1) Parker, $\frac{7}{16}''$ plate.
,, ,, .	,, . .	27·6	26·42	**16·7**	20·80	67	,, $\frac{3}{4}''$ plate.
,, ,, .	,, . .	28·0	29·22	**15·2**	20·22	70	,, $\frac{3}{4}''$ plate.
,, ,, .	,, . .	26·7	28·16	**15·9**	20·12	71	,, $\frac{14}{16}''$ plate.
,, ,, .	,, . .	30·0	25·55	**16·5**	20·10	60	,, $\frac{3}{4}''$ plate.
,, ,, .	,, . .	30·7	34·76	**19·1**	27·03	79	,, $\frac{1}{4}''$ plate.
,, ,, .	,, . .	32·2	34·95	**19·2**	27·12	76	,, $\frac{1}{4}''$ plate.

(1) It is curious that in these experiments the tensile stress on the joint was generally greater (before the joint gave way by shearing) than the ultimate tensile stress of ordinary test specimens of the same material. These experiments were made by Mr. Kirkaldy for the West Cumberland Steel Works.

The average values are as follows :—

Description of Joint.	Authority.	Holes made by.	Shearing Resistance of Rivets in Tons per sq. in.
IRON RIVETS.			
Lap, Double Riveted . . .	Martell & Knight	Punch	19·44
,, Treble Riveted . . .	Parker . . .	Drill	17·27
Butt (one experiment) . . .	Martell . . .	Punch	23·39
STEEL RIVETS.			
Lap, Single Riveting . . .	Sharp and Greig & Eyth	Punch	25·62
,, ,, ,, ...	,,	Drill	23·67
Lap, Double Riveting . . .	Sharp, Martell & Kirkaldy .	Punch	23·99
,, ,, ,, . . .	Sharp & Martell	Drill	24·86
,, ,, ,, . . .	Easton & Anderson . . .	Punch	19·85
Lap, Treble Riveting . . .	Martell . . .	Drill	26·91
,, ,, ,, (chain) .	Parker . . .	Drill	24·65
,, ,, ,, (zigzag) .	,,	,,	20·00
Lap, Quadruple Riveting . .	,,	,,	19·20
Butt, Single Riveting . . .	Sharp and Greig & Eyth	—	22·72
,, Double ,, ...	,,	—	24·93

V. *Resistance to Tearing of Steel Lap Joints.*—There is only a single experiment on a single-riveted steel lap joint. Those on double-riveted steel lap joints are given in the following Table :—

Double-riveted Lap Joints, broken by Tearing.—Steel.

Mode of Riveting.	Holes made by.	Tenacity of Steel. Tons per sq. in.	Stress at Moment of Fracture in Tons per sq. in.			Efficiency of Joint. Per cent.	Remarks and Source of Information.
			Tensile.	Shearing.	Crushing.		
	Punch .	28·93	30·8	18·11	28·61	69	Martell. Plate not annealed. Iron rivets.
	,, .	,,	30·7	18·10	28·50	69	,, ,, ,,
	,, .	,,	30·6	18·00	28·41	69	,, ,, Steel rivets.
	,, .	,,	30·8	18·11	28·61	69	,, ,, ,,
	,, .	,,	31·4	17·41	27·48	69	,, annealed ,,
	,, .	32·50	39·0	19·83	29·10	69·6	Kirkaldy. (Assumed to be not annealed.)
Steam . . .	Drill . .	25·83	26·89	10·97	18·08	62·9	Greig & Eyth. (Assumed not annealed.)
Machine . .	Punch .	25·9	26·94	19·37	33·20	74·0	Easton & Anderson. (Not annealed.) Steel rivets.
,, . .	,, .	25·8	27·03	19·50	33·41	74·5	

The following are average values for double-riveted steel lap joints, derived from the above Table :—

Plates.	Authority.	Apparent Tenacity of Joint. Tons per sq. in.	Tenacity of Plate. Tons per sq. in.	Ratio of Tenacity of Joint to that of Plate. Per cent.
Unannealed	Martell .	30·72	28·93	106·2
,, ...	Kirkaldy .	39·00	32·50	120·3
,, ...	Easton & Anderson	26·98	25·85	104·4
Annealed	Martell .	31·40	28·93	108·5
Drilled, Unannealed . . .	Greig&Eyth	26·89	25·83	104·1

Discarding Mr. Kirkaldy's result, the apparent tenacity of the joints is 21 per cent. greater than the shearing resistance of steel rivets, as deduced from the Table on p. 351.

The following experiments on treble-riveted steel plates have been communicated by Mr. W. Parker. The joints were made by the West Cumberland Steel Company, and the specimens tested by Mr. Kirkaldy. They are interesting not only as filling a gap in the series of experiments, but also from the large size of the joints tested and the thickness of some of the plates.

Lap Joints Treble-riveted, broken by Tearing.
Steel Plates, Iron Rivets.

Mode of Riveting.	Holes made by.	Tenacity of Steel. Tons per sq. in.	Stress at Moment of Fracture in Tons per sq. in.			Efficiency of Joint. Per cent.	Remarks.
			Tensile.	Shearing.	Crushing.		
Machine. .	Drill .	31·2	35·38	18·2	26·79	79	Parker, $\frac{3}{8}''$ plate.
,, . .	Punch .	31·2	23·34	12·0	17·58	52	,, ,, ,,
,, . .	,, .	28·8	22·47	12·2	16·85	54	,, $\frac{7}{16}''$,,
,, . .	Drill .	31·6	32·75	17·6	25·76	73	,, $\frac{1}{2}''$,,
,, . .	,, .	32·7	31·27	16·5	24·59	67	,, ,, ,,
,, . .	,, .	30·9	36·11	16·1	24·32	77	,, $\frac{1}{4}''$,,
,, . .	,, .	30·4	35·00	15·6	23·57	76	,, ,, ,,
,, . .	,, .	28·3	29·88	15·7	23·31	74	,, $\frac{1}{2}''$,,
,, . .	,, .	28·2	30·14	15·8	23·51	75	,, ,, ,,
,, . .	Punch .	31·2	34·58	17·7	26·05	77	,, $\frac{3}{8}''$,, (Annealed after Punching.)

LAP JOINTS TREBLE-RIVETED, BROKEN BY TEARING.
STEEL PLATES, STEEL RIVETS.

Mode of Riveting.	Holes made by.	Tenacity of Steel. Tons per sq. in.	Stress at Moment of Fracture in Tons. per sq. in.			Efficiency of Joint. Per cent.	Remarks.
			Tensile.	Shearing.	Crushing.		
(1) Machine.	Drill .	31·6	**35·88**	23·3	32·96	83	Parker, $\frac{1}{4}''$ plate. (3)
(1) ,, .	,, .	29·1	**33·83**	22·0	22·10	77	,, $\frac{1}{2}''$,, (3)
(1) ,, .	,, .	28·6	**30·47**	22·2	21·24	72	,, $\frac{3}{4}''$,, (3)
(1) ,, .	,, .	27·7	**29·44**	21·5	15·83	69	,, $1''$,, (4)
(2) ,, .	?	27·1	**25·34**	18·4	18·91	70	,, $\frac{7}{8}''$,, (4)

(1) Chain riveting. Three rows of rivets. (2) Zigzag, quadruple riveting.

(3) Joints tested by Mr. Kirkaldy for the Steel Company of Scotland.

(4) Joints tested by Mr. Kirkaldy for Messrs. Denny and Co.

These experiments give the following mean values :—

Riveting.	Authority.	Holes made by.	Apparent Tenacity of Joint.	Tenacity of plate.	Ratio of Tenacity of Joint to that of Plate. Per cent.
Treble, Iron Rivets. .	Parker and Denny .	Punch .	22·90	30·0	76·3
,, ,, ,, . .	,,	Drill . .	32·93	30·5	108·0
Treble, Steel Rivets .	,,	,, . .	30·99	28·8	107·5

VI.—*Steel Butt Joints.* The following Table gives all the results on steel butt joints:—

Double-riveted Butt Joints, broken by Tearing.—Steel.

Mode of Riveting.	Holes made by.	Tenacity of Steel. Tons per sq. in.	Stress at Moment of Fracture in Tons per sq. in.			Efficiency of Joint. Per cent.	Remarks and Source of Information.
			Tensile.	Shearing.	Crushing.		
	Drill. .	36·22	39·25	24·05	34·02	64	Henry Sharp. Steel rivets. One cover.
	Punch .	„	43·63	25·80	37·43	70	„ „ „
	Drill .	„	42·93	13·16	37·20	70	„ „ Two covers.
	Punch .	„	39·11	11·57	33·56	63	„ „ „
	„ .	28·93	22·9	30·36	38·15	61	Martell. Plates annealed. Steel rivets. One cover.
	Drill .	„	24·6	14·02	34·02	63	Martell. Steel rivets. Two covers.
	„ .	„	23·1	13·19	32·00	57	„ „ „
	„ .	„	28·7	16·35	39·68	73	„ „ „
	„ .	„	26·2	17·14	39·79	68	„ „ „
Machine .	„ .	29·15	24·64	14·02	34·00	65	Boyd. Two covers.
„ .	„ .	„	22·87	13·03	31·61	60	„ „
„ .	„ .	„	28·72	16·37	39·70	75	„ „
Machine .	Punch .	36·20	30·8	14·31	41·59	60	(1) Kirkaldy. Two covers. Steel rivets. Plates annealed.
„ .	„ .	„	33·70	15·66	45·49	67	„ „ „ „
„ .	„ .	„	36·81	15·42	44·49	68	„ „ „ „
„ .	„ .	„	37·13	15·55	44·87	68	„ „ „ „
„ .	„ .	„	34·19	14·86	40·38	65	„ „ „ „
„ .	„ .	„	34·92	15·17	41·24	66	„ „ „ „
„ .	„ .	„	33·05	15·77	41·45	63	„ „ „ „
„ .	„ .	„	31·49	15·03	39·51	60	„ „ „ „
„ .	„ .	„	33·00	15·75	37·78	61	„ „ „ „
„ .	„ .	„	32·39	15·46	37·09	60	„ „ „ „
„ .	„ .	„	32·31	11·48	47·82	65	„ „ „ „ (Oval rivets).
„ .	„ .	„	34·17	14·05	50·35	68	„ „
Steam .	Drill .	25·83	30·21	14·30	41·19	60·4	Greig and Eyth. Two covers.
„ .	„ .	„	25·61	11·06	31·89	68·0	„ „
Machine .	Drill .	28·1	22·04	16·4	21·92	59	(2) Parker. Two covers.
„ .	„ .	27·1	22·73	16·8	22·66	63	(2) „ „ „
„ .	„ .	27·2	27·74	21·6	47·95	76	(3) „ „ „

(1) This series of experiments was made for the Bolton Iron and Steel Co.

(2) Joints tested by Mr. Kirkaldy for Messrs. Denny and Co.

(3) Joint tested by Mr. Kirkaldy for Messrs. Jack and Co.

The following are average values for steel butt joints, the plates being assumed to be unannealed if not otherwise described :—

Description.	Authority.	Apparent Tenacity of Joint. Tons per sq. in.	Tenacity of Plate. Tons per sq. in.	Ratio of Tenacity of Joint to that of Plate. Per cent.
UNANNEALED.				
Double-Riveted. One Cover	Sharp . .	41·44	36·22	114·4
,, ,, Two Covers	,,	41·02	36·22	113·2
,, ,, ,, ,,	Martell .	25·65	28·93	88·7
,, ,, ,, ,,	Boyd . .	25·41	29·15	87·2
,, ,, ,, ,,	Greig & Eyth	27·91	25·83	108·0
,, ,, ,, ,,	Parker. .	24·17	27·5	87·8
ANNEALED.				
Double-Riveted. One Cover	Martell .	22·90	28·93	79·2
,, ,, Two Covers	Kirkaldy .	33·66	36·20	93·0

These results differ so much that it has not been thought desirable to take the means.

Mr. Martell's and Mr. Sharp's results give for the apparent tenacity—

Punched Joints . . . . 35·21 tons per sq. in.,
Drilled ,, ... 39·92 ,,

but the individual results are contradictory.

APPENDIX I.

Bending of Thick Plates.

Since the foregoing report was in type, the Reporter has been in correspondence with Mr. R. V. J. Knight as to the experiments on Lap Joints made for him. To confirm his views on the bending action in joints, Mr. Knight kindly carried out the following experiments.

A number of iron castings were made of the form shown in Fig. 12, Plate 35, four being cast together in one moulding box, with the runners arranged as in Fig. 11. Some of the pieces were then bolted together as double-riveted lap joints, others as double-riveted butt joints. The holes for the bolts were drilled and the bolts turned to fit. The nuts were screwed up by hand. The $1\frac{1}{2}$ in. hole in the ends, for fixing the specimen in the testing machine, was coned on each side, so as to leave $\frac{1}{4}$ in. of bearing at the centre of the plate. The pins for these were a loose fit. The butt joints had wrought-iron straps on each side, $\frac{1}{2}$ in. thick. With the first two tons of stress, the lap joints took the position shown in sketch, Fig. 13, which position they retained till they broke. The results were as follows:—

1st Moulding Box . .	1 Lap Joint broke with 11 tons. 1 Butt Joint. Defective.
2nd "	1 Lap Joint broke with $10\frac{3}{8}$ tons. 1 Butt Joint " " $21\frac{1}{8}$ "
3rd "	1 Lap Joint " " 10 " 1 Butt Joint " " $20\frac{1}{8}$ "

Mean breaking weight, Lap Joints 10·46 tons
" " " Butt " 20·62 "

This shows conclusively that in these experiments the deviation of the resultant stress from the centre of figure, at the section of fracture, had caused a loss of about half the strength in the lap joints. Further, as these joints were held in the testing machine in a perfectly satisfactory manner, the loss of strength must be ascribed entirely to the form of the joint.

The bolts were uninjured by the load. The cast iron was of first class quality, fine grained but not hard. The fractures were without flaws.

To gain some further information, the remaining pieces were

bolted together in the form of single-riveted lap joints. The results were as follows :—

Cast in 1st box	(1)	Broke with $7\frac{3}{4}$ tons.
,, ,, ...	(2)	,, ,, 8 ,,
,, ,, ...	(3)	,, ,, 8 ,,
Cast in 2nd box.	(1)	,, ,, $8\frac{1}{4}$,,
,, ,, ...	(2)	,, ,, $8\frac{1}{2}$,,
,, ,, ...	(3)	,, ,, $8\frac{1}{2}$,,
Cast in 3rd box.	(1)	Defective.
,, ,, ...	(2)	Broke with $7\frac{3}{4}$,,
,, ,, ...	(3)	,, ,, $8\frac{1}{4}$,,
Mean breaking weight . .		8·12 tons.

This shows a still greater loss of strength than in the case of double-riveted joints.

Undoubtedly these results appear, at first sight, strongly to confirm the opinion that the form of the lap joint reduces by 50 per cent. the strength of the metal of the joint, apart from the further loss due to the metal punched out to form the rivet holes. But it is so difficult to accept this result for ordinary wrought-iron joints, in face of the numerous experiments which show a much smaller loss, that the Reporter is unable to accept these experiments on cast iron as quite equivalent to experiments on wrought iron.

Wrought iron elongates considerably when strained beyond the elastic limit, especially near the breaking point, while the elongation of cast iron is not much greater beyond than within the elastic limit. The inequality of the distribution of stress on the section of fracture, due to a given deviation of the position of the resultant stress from the centre of the section, is probably much less for wrought iron than for cast iron. Besides this, it must be remarked that the deviation of the line of resultant stress is proportionately as great for thin as for thick lap joints, and the reduction of strength which Mr. Knight has found in $\frac{7}{8}$ in. and 1 in. joints ought to be found also in joints $\frac{3}{8}$ in. and $\frac{1}{2}$ in. thick.* Within the elastic limit, at all events, the stress would be as unequal in thin as in thick joints, and it is not easy to see any reason why it should be different at rupture. But the experiments on thin joints are numerous, and exhibit no great reduction of the apparent tenacity of the metal, which can be attributed to the form of the joints.

* Mr. Knight does not however assent to this opinion.

Let P be the resultant stress on the section, and r the distance of its point of application from the centre of the section; let A be the area, and Z the modulus of the section. Then so long as the limit of elasticity is not passed, the maximum stress is,

$$f_{max} = \mathrm{P}\left(\frac{1}{\mathrm{A}} + \frac{r}{\mathrm{Z}}\right)$$

The mean stress is $f = \frac{\mathrm{P}}{\mathrm{A}}$. Hence, the mean stress is less than the maximum in the ratio

$$\frac{f}{f_{max}} = \frac{1}{1 + \frac{\mathrm{A}r}{\mathrm{Z}}}$$

If r is a constant fraction of the thickness t of the plates, as mentioned above, this ratio is independent of the thickness, and the mean stress for a given maximum or breaking stress would be the same, whether the plates were thick or thin. Now in Mr. Knight's experiments on cast iron r = about $\frac{1}{3}t$ for the double-bolted, and $\frac{1}{2}t$ for the single-bolted specimens. Then, putting b for the breadth of the specimen,

$$1 + \frac{\mathrm{A}r}{\mathrm{Z}} = 1 + \frac{6\,btr}{bt^2} = 1 + \frac{6\,r}{t}$$

= 3 for the double-bolted, and 4 for the single-bolted joints. Hence, if the limit of elasticity had not been passed, the apparent tenacity should have been $\frac{1}{3}$ the real breaking strength for the former and $\frac{1}{4}$ for the latter. These ratios probably do not very widely differ from those actually found (about $\frac{1}{2}$ and $\frac{1}{3}$ respectively), for the real tenacity was probably a little higher than the tenacity in the butt joints. Hence for cast iron the distribution of stress is nearly as unequal when the bar breaks as if the material were perfectly elastic.

In the above calculation it is assumed that there is no actual bending of the cast iron, which would sensibly alter the position of the resultant stress with relation to the section of the joint. In other words, r is taken to be the same at fracture as before testing the specimen. This is nearly true for cast iron, but with wrought iron joints there is considerable bending, which alters the position of the resultant stress on the sections of fracture to an unknown extent.

APPENDIX II.

Memorandum of Suggestions as to Experiments to be undertaken on Riveted Joints.

The suggestions on which this memorandum is based were submitted to the Committee at their Glasgow Meeting. It was there decided that the experiments should be restricted for the present to steel plates, and the Reporter was requested to modify the suggestions in accordance with this decision. Professor Kennedy having offered to carry out for the Committee any experiments for which his machine is adapted, the Reporter was requested to consider the precise dimensions of the specimens which would be suitable for experiment. The limit of the breaking strength of the specimens is fixed at 45 tons. Taking the ultimate strength of steel at 30 tons per sq. in. in tension and 24 tons in shear, the specimens should be so designed that the weakest section in tension should not exceed 1·5 sq. in., and the weakest section in shear 1·8 sq. in.

A review of past experiments reveals great discordance in results arrived at under conditions intended to be the same. These discordances may be due in some cases to real differences in the quality of the materials tested. Two specimens from the same plate do not always break with the same load; and much more may plates of different make be expected to vary. Now as the object of experiments on riveted joints is chiefly to determine the proportions of the joints, and only secondarily to determine the strength of different qualities of material, it would appear desirable for the Committee to select a very uniform quality of steel plate and steel rivet bar, and to use these alone, at least in all the earlier experiments. The more uniform the quality, the fewer the experiments necessary to give a trustworthy average result. At a later stage it may be useful to experiment on the effect of riveting in the case of inferior or more variable materials.

For the purposes of these experiments it would seem desirable to have three thicknesses of plate, and the following are proposed:— $\frac{1}{4}$ in., $\frac{3}{8}$ in., $\frac{1}{2}$ in.

The rivets would commonly vary for these plates from $\frac{1}{2}$ in. to $\frac{7}{8}$ in. diameter. But as the proper size of rivet is one of the problems to be solved, it would be desirable to have steel rivet bars of $\frac{7}{16}$ in., $\frac{9}{16}$ in., $\frac{11}{16}$ in., $\frac{13}{16}$ in., $\frac{15}{16}$ in., and $1\frac{1}{16}$ in. diameter, for use in different experiments.

To render any experiments made by the Committee comparable with previous experiments, and useful as guides in designing, the absolute tenacity and shearing strength of the steel must be known. Experiments should therefore be made on pieces of each thickness of plate, and on specimens of the rivet bars.

Tenacity of Plates.—The specimens of plate should be of the form shown in Fig. 14, Plate 35, arranged so as to be held in the machine by pins, which are nearly equivalent to knife-edges. The method now often adopted of holding plates by friction, using wedges which grip the plate, appears to the Reporter to be essentially unreliable for plates wide in proportion to their thickness, although it may answer very well for round or square bars.

For uniformity the specimens might all be of the form shown in Fig. 14, the variable dimension b being made as follows:—

	In.	In.	In.
Thickness of Plate	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$
Width (b)	$1\frac{3}{8}$ & 4	$2\frac{1}{16}$ & $3\frac{1}{2}$	$2\frac{3}{4}$
	Tons.	Tons.	Tons.
Probable breaking weight ..	10 & 30	23 & 39	41

There is considerable danger of the holding pins tearing out in specimens of this form, owing to the inequality of stress in the ends, especially in thin plates. If this occurs, it is better prevented by doubling the thickness at the ends, by riveting an additional plate upon them, than by a greater enlargement of the ends. It would probably be still better to rivet a plate on each side, so as to distribute the pressure on the pin more uniformly, and to diminish crushing.

In the recent experiments of Mr. Knight on cast iron, the holes for the holding pins were coned on each side so as to ensure the

pressure coinciding with the centre of the plate. This is a desirable arrangement where it can be adopted; but with steel it would probably be quite ineffective, from the crushing of the plate round the pin.

It would be useful to test the tenacity of the rivet steel, and for this purpose the specimens should be prepared as in Fig. 15, Plate 35, and to the following dimensions; the thread to be Whitworth's.

Diam. of Original Bar.	$\frac{11}{16}$ in.	$\frac{15}{16}$ in.	$1\frac{1}{16}$ in.
Dimension D	$\frac{5}{8}$	$\frac{3}{4}$	1
a	2	2	$2\frac{1}{2}$
l	12	12	12
d	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{13}{16}$

Shearing Resistance of Rivet Steel.—The Reporter has no information as to the best form of specimens for testing shearing resistance. Probably the experiments mentioned below, on butt joints with double covers, would be sufficient to determine the shearing resistance; but special experiments, if they can be arranged for, would be desirable.

Experiments on Riveted Joints.—Special precautions suggested by previous experiments.—Having secured immunity from errors due to variation in quality of material, it must next be considered what special precautions require to be taken in experiments on riveted joints, the neglect of which in previous experiments has led to discordant results. No doubt some of the discordances in past experiments must be attributed to errors in testing machinery, or to errors of measurement. In regard to the former no remark is necessary, but in regard to the latter it may be observed that the specimen should be measured before riveting up.

As to the design of all specimens tested, one general rule must

be observed. The centre line, drawn through the centres of the holding pins, must pass :—

(*a*) Through the centre of figure of the weakest section of each plate and cover.

(*b*) Through the centre of figure of the aggregate rivet sections, or, in butt joints, of the aggregate rivet sections on each side of the joint.

If these conditions are not fulfilled, the strength of the joint is diminished by the irregular distribution of the stress.

One more preliminary remark may be made. The object of experiments on complete riveted joints is to determine two limits of stress, viz. the tenacity of the plates and the shearing resistance of the rivets. When these are known for any given form of joint, the design of the joint is a mere matter of algebra. In many previous sets of experiments only one of these limits has been ascertained, and then one of the constants necessary is undetermined. Now neither of these limits of stress will be sensibly altered, in any given form of joint, by small variations of the pitch or rivet diameter. Hence all joints should be designed in pairs, one being intended to give way by tearing and one by shearing. The excess of shearing resistance in the one, and of tensile resistance in the other, will not sensibly affect the stresses to be determined.

Before however complete riveted joints of any form can be designed, there are one or two preliminary questions to which an answer must be found; and experiments with reference to these naturally take precedence of experiments on complete joints.

Influence of the mode in which the Rivet Holes are made on the Tenacity of the Plates.—Numerous experiments have been made, showing a considerable loss of strength in punched plates, and a small loss (sometimes a small gain) in drilled plates. These are so numerous that the Committee may deem it unnecessary to repeat them; but in one respect experiments of this kind have been made imperfectly. Generally a narrow strip of plate has been taken and a single hole punched or drilled in it, and it has then been broken in

the testing machine. Probably however the action of the punch is very different in the case of a narrow plate of this kind, which permits some lateral expansion, and in the case of a broad plate with a row of holes along its edge. Further, it is by no means certain that the strength of a specimen such as *a*, Fig. 16, Plate 35, is the same as that of a strip with equal effective section such as *b*. Considering the large deformation which takes place in tough materials at the period of fracture, a sensibly different distribution of stress might arise in these two cases, from the different facility they present for lateral contraction. If therefore the Committee think it worth while to experiment on this point, the specimens should be made to represent as perfectly as possible portions of a long joint. To secure this the specimens must be cut (1) from a plate which has had a row of holes formed by drilling or punching at a distance corresponding to the pitch, (2) so as to leave a semi-hole in each edge of the specimen. Fig. 17, Plate 36, gives a diagram of such a set of specimens. For $\frac{1}{4}$ in. and $\frac{3}{8}$ in. plates the following would be the areas of the section of fracture, and the breaking weights at 30 tons per sq. in.

Specimen No.		1	2	3	4
$\frac{1}{4}$ in. plate	Section, square inches	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{3}{4}$	1
	Breaking weight, tons	7·5	15	22·5	30
$\frac{3}{8}$ in. plate	Section, square inches	$\frac{3}{8}$	$\frac{3}{4}$	$1\frac{1}{8}$	$1\frac{1}{2}$
	Breaking weight, tons	11·25	22·50	33·75	45

It may eventually be desirable to repeat these experiments with holes proportionate to the thickness of the plate.

These experiments would have a special value in this case, over and above the determination of the loss due to punching and drilling. They will enable the Committee to distinguish exactly between the loss due to this cause and the loss due to other causes, such as crushing and bending, in the experiments suggested below. Without a separate and accurate determination of each special source of injury

to the strength of the plate, the determination of all of them becomes uncertain.

Influence of the Crushing Pressure on the Tenacity of the Plates.—The question whether the crushing action of the rivet on the plates seriously diminishes the strength of riveted joints, when the intensity of crushing pressure is above a certain limit, has never been satisfactorily determined. Now the intensity of crushing pressure increases with the ratio of diameter of rivet to thickness of plates. It is therefore only necessary, in experimenting on this question, to design a series of joints with a given thickness of plate and with different rivet diameters. The tearing and shearing area should be nearly equal, as in actual joints; but as crushing action may affect the strength either of the plate or the rivets, two sets of joints should be prepared, one having an excess of shearing and the other of tearing resistance.

As the distribution of stress between rivet and plate is different with different forms of joint, it would seem best to have a set of lap joints, which give the greatest inequality of stress, and also a set of butt joints with double covers, which give the most uniform distribution of stress possible in actual joints. As exact information about crushing pressure is wanted, all the rivet holes should be drilled; the size of the rivet holes can then be exactly determined. With punched holes the experiments would be much rougher and less decisive. The specimens should be of the form shown in Fig. 18, Plate 36.

The following Table of dimensions in inches (in accordance with Fig. 18) gives a scheme of experiments on joints in $\frac{3}{8}$ in. plates. There would be four series of specimens: (1) lap joints to break by tearing; (2) lap joints to break by shearing; (3) butt joints to break by tearing; (4) butt joints to break by shearing.

Thickness of Plate. t.	Diam. of Rivet. d.	Ratio * $\frac{f_c}{f_s}$	Width of Plate for One Rivet, b.		Probable Breaking Weight.
			Tearing Series.	Shearing Series.	Tons.
$\frac{3}{8}$	$\frac{3}{8}$	0·78	0·50	0·75	2·6
,,	$\frac{1}{2}$	1·08	0·82	1·00	4·8
,,	$\frac{3}{4}$	1·56	1·50	2·00	10·6
,,	$\frac{7}{8}$	1·85	1·80	2·375	14·4
,,	1	2·15	2·25	3·125	19·2
,,	$1\frac{1}{8}$	2·45	2·50	4·000	24·0

* f_c = crushing stress, f_s = shearing stress per sq. in.

As the question involved in these experiments is really important, it would be desirable to repeat the experiments with joints of double the width and having two rivets. The scheme for these would then be :—

Thickness of Plate. t.	Diam. of Rivet. d.	$\frac{f_c}{f_s}$	Width of Plate for Two Rivets. b.		Probable Breaking Weight.
			Tearing Series.	Shearing Series.	Tons.
$\frac{3}{8}$	$\frac{3}{8}$	0·78	1·00	1·50	5·2
,,	$\frac{1}{2}$	1·08	1·64	2 00	9·6
,,	$\frac{3}{4}$	1·56	3·00	4·00	21·2
,,	$\frac{7}{8}$	1·85	3·60	4·75	28·8
,,	1	2·15	4·50	6·25	38·4

It would be useful in these experiments to scribe a line across the edges of the joints before beginning to load, and to attempt by this means to ascertain at what point slipping of the plates commenced, and what total amount of slipping occurred in consequence of the gradual crushing of plate and rivet.

Influence of Bending Action on the Strength of the Joint.—An important question arises out of the experiments on thick lap joints, namely whether the bending action which occurs during the application of the load seriously diminishes the strength of the joint. Further, although it would seem, theoretically, that any loss from bending action must be proportionately the same for joints of different thicknesses, yet the experiments which raise this question seem to show that the loss is much greater for thick plates.

To investigate this point, a series of joints precisely like those in Fig. 18, Plate 36, are required, one set being lap joints, the other set butt joints with double covers. For the reasons given above, the holes should be drilled. The following scheme gives the dimensions of the joints in inches, supposing one rivet in each joint:—

Thickness of Plate. *t*.	Diam. of Rivet. *d*.	Width of Plate for One Rivet. *b*.		Probable Breaking Weight.
		Tearing Series. Inch.	Shearing Series. Inch.	Tons.
$\frac{1}{4}$	$\frac{5}{8}$	$1\frac{3}{8}$	3	7·2
$\frac{3}{8}$	$\frac{3}{4}$	$1\frac{1}{2}$	2	10·6
$\frac{1}{2}$	$\frac{7}{8}$	$1\frac{1}{2}$	2	12·5
$\frac{3}{4}$	1	$1\frac{5}{8}$	$2\frac{1}{8}$	19·0

A similar set of joints with two rivets would have the following proportions:—

Thickness of Plate. *t*.	Diam. of Rivet. *d*.	Width of Plate for Two Rivets. *b*.		Probable Breaking Weight.
		Tearing Series.	Shearing Series.	Tons.
$\frac{1}{4}$	$\frac{5}{8}$	$2\frac{3}{4}$	6	14·4
$\frac{3}{8}$	$\frac{3}{4}$	3	4	21·2
$\frac{1}{2}$	$\frac{7}{8}$	3	4	25·0
$\frac{3}{4}$	1	$3\frac{1}{4}$	$4\frac{1}{4}$	38·0

In making the above suggestions for the initial experiments, the Reporter has tried to arrange experiments by which perfectly definite questions should be put in each case. With the enormous number of experiments already made, it is almost useless making new experiments the conditions of which are complex or indefinite. *It must be quite understood however that these are strictly preliminary experiments, and should be followed by experiments on ordinary forms of joint, designed in accordance with the limits of stress determined in these preliminary experiments.* Whenever those final experiments are undertaken, it will probably be necessary to have recourse to a testing machine giving a pull of 100 tons, at all events if the joints are of steel.

The experiments here proposed, if carried out at all, should be proceeded with cautiously. Each set of experiments will afford data which will be a guide in designing the exact proportions of the next set. The dimensions given above must be considered as simply first approximations, to be revised by those who are in charge of the experiments.

W. C. UNWIN, *Reporter.*

November, 1879.

ON THRASHING MACHINES.

By Mr. W. WORBY BEAUMONT, of London.

It is not the Author's intention to occupy time or space with the history of the invention and development of the Thrashing Machine; as, although of much interest, it is perhaps already sufficiently accessible in the two leading English engineering journals for the second half of the year 1879, and in previously existing writings. Probably therefore no apology is needed for dealing with modern machinery only.

There is perhaps no single machine designed to carry out any series of operations or processes, in which so many conditions and circumstances are involved, and have to be fully considered and provided for, as in the finishing thrashing machine.

It is thus a somewhat complicated piece of combined mechanism, which is purely the result of experiment, unaided by any direct application of theory to the phenomena or laws upon which the successful performance of its various and complex functions depends. The perfection of the modern machine has only been realised at the expense of nearly forty years of experiment and careful observation of practical working, carried on by English agricultural engineers in almost all parts of the world. In scarcely any particular has it been possible to arrive at the necessary proportions or dimensions except by tentative methods. The inter-relation of the various parts is of so complex a nature, that it has been impossible to predict the results of the step-by-step modifications and additions, by which alone success has been achieved in dealing with the various crops of all countries. Not only does every country produce even the same corn with straw or stems of different lengths, with varying proportions of grain to straw, of grain to ear, and of beard and chaff to ear, and with different proportions of weeds and seeds in the crop; but the circumstances of dry and wet seasons, and of heat or cold, affect the

conditions under which the thrashing, cleaning, and separation of the grain and seeds can be effected. In England thrashing is performed at almost all times of the year; and the crop is consequently in different states of dryness, depending upon the season and weather when it is thrashed, the time it has remained in stack, the part of the country in which it has been grown, the situation in which the stack has been placed, and, if thrashed directly after harvest, the amount of rain and of sunshine during harvest. In most foreign countries it is thrashed when harvested, and is consequently very often extremely dry and very brittle; while the quantity of weeds, grown and collected with the crop, is sometimes more than the crop itself.

These facts give a faint idea of the chief causes of the manifold difficulties and conditions involved in producing successful thrashing machines; they will however be better appreciated when the details by which these difficulties are overcome have been described.

The primary operations performed in thrashing are—

1. Separation of the grain from the ear and straw;
2. Separation of the grain from short broken straw (cavings) and pieces of broken ear (chobs), and from the chaff;
3. Separation of the grain from dirt and seeds;
4. Separation of the grain into different qualities.

In most countries these involve—

1. Thrashing the whole crop, with greater or less length of straw, by passing it between a fixed and a rapidly revolving ribbed surface;
2. Shaking the straw, to remove any grain, seeds, chobs, and chaff that may be carried by it;
3. Passing the whole of the products of thrashing, except the straw, over rapidly reciprocating riddles and sieves, in presence of the blast from one or more fans;
4. Passing the grain through a cylinder provided with revolving beaters or arms, to remove any firmly adhering chaff, awns, or beard, followed by final sifting on secondary sieves;
5. Passing the grain through a revolving screen, for sorting.

The parts by which these operations are performed, and their arrangement, may now be described.

Ransomes' Machine.—In order that this paper may be illustrative of the best English practice in the year 1880, the Author proposes to describe the arrangement of the machines by several of the best known makers: commencing with the finishing machine made by Messrs. Ransomes Head and Jefferies, simply because the Author happened to be first acquainted with the machines made at their works, where moreover the first portable steam thrashing machine, it is believed, was made.

This machine, of the size having a drum 4 ft. 6 in. long, is illustrated in Figs. 1 to 4, Plates 37 to 39. This is only one of many different sizes and arrangements of machines made by this firm, according to the practice of all makers, to suit the requirements of different countries; but it has been adopted by the Author throughout for purposes of comparison. The arrangement and the purposes of the parts will be best understood by following the straw, grain &c., through the machine.

Fig. 1, Plate 37, is an exterior side elevation of the machine, showing the side opposite to that of the drum pulley *d*, Fig. 3, by which the whole machine is driven. Fig. 2 is a longitudinal sectional elevation, taken a short distance within the side shown in Fig. 1. Fig. 3 is a transverse section of the machine at the hinder end, taken through a line a little within the end framing, and looking from behind. Fig. 4 is a transverse section through the shakers and main shoe, taken on a line a little in front of the drum, and looking from behind.

The man feeding stands in the feeding box A^1, Fig. 2; and the sheaves of corn after the binders have been cut, or the corn of whatever sort in a loose form, is handed to him by other workmen standing on the top or platform of the machine. The feeder then passes it into the drum mouth A, with as much regularity as possible, over the feeding board A^2. It is then caught by the drum B and rapidly carried between it and the concave B^1. The grain is knocked and to some extent rubbed out of the ear, and the ear

more or less broken and separated from the straw, as it passes between the drum and concave. Most of the grain falls through the concave grating, and the rest passes on with the straw to the shakers C, Figs. 2 and 4; the straw carrying with it some grain, and a good deal of the chobs and cavings. All these are shaken from the straw on the shakers, and pass through them, on to and down the oscillating board D, whence they fall on to the upper end of the riddle surface E. The greater part of the grain, seeds, chaff &c., which falls through the concave, passes on to the oscillating board D^1, and thence also on to the riddle surface E. The straw, from which all grain &c. has now been separated, passes upwards along the shakers and falls over their upper end; while the grain, seeds, chaff, and chobs pass through the riddle E, Figs. 2 and 4. The cavings pass down the riddle surface, and fall off at the lower end. The grain, seeds, chaff, and chobs pass down to the bottom of the oscillating board F, most of the small seeds and dirt being separated in the passage thereto by falling through the perforated plate or sieve over the spout W, which conveys them away. The remainder of the material, including all the grain, chaff, chobs, and some seeds, passes to the end of the board F, and falls down the inclined board X on to the upper sieve G. Through this sieve most of the grain falls to the bottom of the lower shoe at Y, while a blast of air from the fan H assists in the sifting by blowing the chaff away from the sieve, especially that which tends to fall off its end, in the direction of the upper arrow. Some of the small pieces of imperfectly thrashed ears and grain, with adhering chaff, are also blown in this direction; but owing to their weight they are not carried beyond the stop bar on the board Z. From the board Z these chobs pass down the inclined plane to the second and lower sieve G^1; the heavier chobs from the end of the upper sieve also fall down to G^1, some grain falling with them. On G^1 the sifting is repeated, the grain falling to the bottom of the shoe, and the whole of the chobs falling into the chob-spout V, whence they drop into baskets and are again passed through the drum for a second thrashing. There now remains only the grain and some of the larger seeds to be dealt with, the grain having received its first dressing.

For the second dressing and screening, the grain passes through the spout I to the bottom of the elevator box, and is thence taken by the cups of the elevator J to the top of the machine, and delivered into the cylindrical part of the awner K, Figs. 2 and 3. When however the grain is remarkably uniform in quality, and the crop very clean as respects freedom from weeds, and when it is intended to dress the corn (if that is further necessary) in a separate dressing machine, the grain is allowed to pass at once out of the machine from the elevator spout to the sack spouts Q; for which purpose a slide is provided at P in Fig. 2. The same remark applies when beans are thrashed. Otherwise the grain is passed by revolving arms through the awner K, in which any firmly adhering chaff is rubbed off the grain, and the smut balls are broken. Thence it falls through a spout on to the upper sieve in the second jog shoe L, Figs. 2 and 3, and is successively sifted by the several sieves shown in cross section in Fig. 2; the larger seeds and any stones being rejected and passed down the spout M, while the grain goes through the spout N into the rotary screen O. At H^2, Fig. 3, is a second fan, from which a blast is directed between the sieves in the jog shoe L; and by this blast all dust (some of which results from the broken smut balls), together with the chaff or beard which has been rubbed off in the awner K, is blown off through the dust spout R, Figs. 1 and 3. In the screen O, Fig. 3, the smallest corn drops at once through to the spouts Q Q, and forms the third quality. The grain next in size drops through the screen over the middle spout Q^1; and the largest grain, which drops through the screen last, or falls out at its end, and which forms the first quality, passes to the sacks through the spouts Q^2 Q^2.

To provide room for the men working on the top of the machine in attendance upon the feeder, the platform is increased in width by boards (not shown in the drawings), which are hinged to the top edges of the frame, and supported at their extremities by struts resting on the bottom members of the frame. These boards extend to the length indicated by the vertical boards, shown at the top of the machine in Fig. 1, Plate 37.

The drum B in this machine, Fig. 2, Plate 38, has a width of 4 ft. 6 in., and consists of six beaters mounted upon iron-faced beater bars,

which are fastened by hook bolts to three flanged plate drumheads, and to two intermediate wrought-iron rings. The plate drumheads are fastened to cast-iron bosses keyed on the drum spindle, which revolves in long bearings fixed to a cast-iron bearing plate P, Fig. 1, bolted to the two vertical frame pieces. The beaters are themselves long screws made by twisting rolled bars of the section shown in Fig. 7, Plate 39. After these have been twisted and straightened, grooves are cut in them at the necessary distances apart, to receive the hook bolts by which they are held on the drum.

The concave B^1, Fig. 2, is made in two parts connected by a long transverse pin or bolt, a little below the centre of the cross section of the concave. It consists of two main end pieces of wrought iron, and a number of intermediate similar shaped ribs, forming a support to the ribs running transversely to the machine, which are seen in section in Fig. 2. These latter ribs are perforated near their upper edges, and receive curved wires generally about $\frac{5}{16}$ in. in diameter. A coarse strong grating is thus formed, which is adjustable as to distance from the drum at three points, namely in the upper part, a little below the middle, and at the forward end of the bottom. The long bolts on which the segments rest pass through the outside of the machine, and are there held by the three sets of adjusting gear G G G, shown in Fig. 1, two being below the drum spindle and one above, and all attached to iron bearing plates. The lower part of the concave is made somewhat more open than the upper part. The distance at which the concave is set from the drum is always greater at the top than at the centre, and at the bottom or forward part it is least, the actual distance varying with the nature and condition of the grain to be thrashed. For wheat, oats, and barley, in average condition and quantity of straw, it is usually set $\frac{3}{8}$ in. from the drum beaters at the bottom, from $\frac{5}{8}$ in. to $\frac{3}{4}$ in. at the middle, and about $1\frac{1}{2}$ in. at the top. For very damp or very dry corn however it is set closer or wider respectively, as experience dictates. Sight holes at the sides of the machine are provided, through which the distance between the bottom, or middle, of the concave and the drum may be seen while making adjustments, the distance at the top being seen from the drum mouth.

The advantage of the screw or twisted drum-beater, Fig. 7, Plate 39, is that, besides being a good thrasher, it can be turned as wear takes place, and from two to four new faces presented, according to the care taken by the attendants in fixing it. Moreover, as the man feeding the machine habitually feeds more towards the centre and one end of the drum, rather than uniformly throughout its whole length, the beaters can be changed end for end with advantage.

As the drum runs at a very high velocity, it is necessary that it should be most carefully balanced, and that every part should be of good material and firmly connected. The speeds and leading dimensions of the chief parts of the machines here described will be referred to further on.

It has been mentioned that the grain, as the corn or crop passes between the drum and concave, is knocked and perhaps to some extent rubbed out of the ear ; but it will be seen from the construction of these parts, and from the fact that the velocity of the drum periphery is 6047 feet, or considerably over a mile, per minute, that the rubbing can only be that effected by the straw as it is whisked round from the drum-mouth to the shakers.

In leaving the drum and the directing plate, which is curved upwards a short distance from the concave, the straw flies upwards ; its fall upon the ends of the shakers C is determined by the inclined board B^2 overhead, Fig. 2, which is adjustable as to inclination. The straw is checked from ascending the shakers too rapidly by two swinging shutters B^3, placed across the whole width of the machine, as shown in Fig. 2. The shakers consist of four sets of reciprocating wooden frames or boxes C C, Fig. 2, the upper parts of which are filled in with small transverse strips of wood, placed at a short distance apart, so as to form a grating. These boxes are mounted upon brackets carrying bearings, and worked by two sets of cranks S S, Figs. 2 and 4, Plates 38 and 39. The cranks are set at equidistant angles of 90°. Each shaker box or section thus receives a similar compound motion, by which the straw is thoroughly shaken and carried forward, while the shaking is increased by a deeply-notched longitudinal piece placed along the middle of the top of each shaker frame, Fig. 2.

The shogging or jog board D, Fig. 2, Plate 38, which receives all that is shaken from the straw, and the jog board D^1 which receives all the grain &c. that has dropped through the concave, take their motion from the crank T; as does also the wood riddle E, which is connected with these boards, so that their motions are simultaneous. The rod by which they are connected with the crank T is fixed under the board D^1, and is thinned or flattened near the point of fixture; being thus made flexible, it needs no joint. The riddle surface, which is usually constructed of mahogany or walnut, is grooved in the direction of the length of the machine, as shown in transverse section in Fig. 5, Plate 39; the grooves are of 1 in. pitch, and the holes of different sizes from $\frac{1}{2}$ in. to $\frac{7}{8}$ in.; the smallest sizes being for such grain as wheat and rye. The jog boards and riddle are suspended at each end by hangers U U, Fig. 1, which consist of thin strips, usually of tough ash. The lower jog board F, and the other parts of the lower shoe Y, are suspended by similar hangers U^1 U^1. This shoe Y also receives its motion from the crank T through a flexible rod, as shown in Fig. 2.

When thrashing oats the seed-sieve at W, Fig. 2, is taken out, and a blank plate put into its place; but the seed-sieve is left in for thrashing wheat and barley. The lower sieves G and G^1 vary in mesh from $\frac{1}{4}$ in. to $\frac{1}{2}$ in. according to the grain being thrashed. The strength of the blast through and past these sieves is regulated by a slide inserted near I, Fig. 2. This blast must be regulated with great care, so that all the grain, including the small and light grain and chobs, may drop within the bar Z, while the chaff from the upper sieve must be carried beyond that bar. The construction of the fan H is sufficiently shown in the section, Fig. 2.

The elevator J consists of a leather belt, provided with a number of tin-plate cups of the transverse section indicated in Fig. 2, Plate 38, and enlarged in Fig. 24, Plate 45; the speed of the belt is made sufficient to elevate the grain from a full crop. The awner K is provided with revolving knives and beaters, which may be used in part and separately, or all together, at the discretion of the attendants of the machine, and according to the character and condition of the grain being dressed. If the grain is smutty or brittle, it is usually

not passed through the awner, but delivered direct to the second dressing shoe L, Figs. 2 and 3, Plates 38 and 39, the sieves in which vary according to the grain to be dressed, being for instance of $\frac{1}{2}$ in., $\frac{1}{4}$ in., or $\frac{3}{16}$ in. mesh. Some sieves are made of perforated iron or zinc, others are of woven wire, others again are made with parallel wires. For barley, which is difficult to awn, and for wheat to which there is much firmly adhering chaff or white coat, the whole of the beaters are sometimes used in the awner, instead of the knives. The awns and chaff thus removed have to be blown from the sieves in the second dressing shoe L by the blast from the fan H^1; and the force of this blast must be carefully regulated so that no grain is carried away. The screen O is a rotary cylindrical wire screen, the wires being adjustable as to pitch, to suit the grain to be screened. At the other end of the machine, near the front road-wheels, is a board *b*, Fig. 2, hinged at the upper part, and lowered into a vertical position when thrashing, so as to prevent a mixture of the chaff with the cavings.

Clayton and Shuttleworth's Machine.—Figs. 8, 9, and 10, Plates 40 to 42, illustrate a 4 ft. 6 in. machine by these makers, which is made in two sizes, light and heavy. Most of the foregoing description applies to this; but it will be seen that there are several essential points in which the arrangement, as clearly shown by these drawings, differs from that already described. First amongst these must be noticed that the shorter portion of the length of the concave B^1 is uppermost. As most work is done here, and as re-adjustment is here most often necessary, this may be advantageous, especially when very much barley has to be thrashed. The drum beaters are also different; instead of being long screws, they are rolled steel bars or plates, with equidistant tooth-like projections, as shown in Fig. 11, Plate 42. These beaters have much wider faces than those previously described, which is an advantage for some grain, though not perhaps for all. The shakers C are also different in construction: the path of motion of each shaker frame or box, instead of being a circle, is reciprocating at the lower or upper end alternately, a complete circle as it follows the crank at the centre, and an ellipse at the other

end, the frames or boxes being supported on rockers alternately at the lower and upper end. There are five shaker frames C, as seen in Fig. 10. The holes in the wood riddle E in Messrs. Ransomes' machine are cylindrical, Fig. 5, Plate 39; those of Messrs. Clayton and Shuttleworth are countersunk, Fig. 12, Plate 42. For wheat the holes in the wood riddle, usually of $\frac{5}{8}$ in. diameter, are not countersunk, but are bored through the wood at a slight angle, as shown in Fig. 13, Plate 42, a device first employed by Mr. E. Humphries. The inclination of the holes is such as to meet the movement of the straw, and the object is that any short straw entering a hole shall not fall through, but be caught and driven back by the sloping side of the hole opposed to it.

In the machine shown by these drawings the elevator box J is placed outside the frame, Fig. 8, Plate 40; but in other examples it is placed within the frame, as in Ransomes' machine, Figs. 2 and 3. From Fig. 9 it will be seen that a somewhat different arrangement is adopted for removing the seeds; instead of being carried off from the jog board F, through a sieve towards its lower end, as at W, Fig. 2, the seeds pass, with the grain, chobs, and chaff, through the sieves in the lower shoe, and are carried off by a spout W, Fig. 10, under the lowest of these sieves. From Fig. 9 it will also be seen that the chaff riddle G, or the riddle from which most chaff is blown away, is adjustable as to inclination. The wide working platform previously alluded to, overhanging the sides of the machine at top, is well shown in the transverse section, Fig. 10. The construction of the side frames of these two machines is somewhat different as respects verticals, diagonal struts, and braces, the necessary rigidity being obtained in the two machines in different ways. Fig. 10 is a transverse section at XX in Fig. 9; and these two drawings so clearly show the general arrangement of the machine that it is unnecessary to describe it in further detail.

As the Author has already stated, almost the whole of these details are subject to modification to meet the requirements of different countries and practices; and the relative dimensions are also subject to large modifications. In Australia, for instance, where the corn is generally cut off near the ear, all the riddling surfaces and the parts constituting the dressing apparatus must be very large.

Garrett's Machine.—Figs. 14, 15, and 16, Plates 43 and 44, show an arrangement of machine which differs very largely from either of those yet described. They represent a machine made in two sizes by Messrs. Richard Garrett and Sons, of Leiston, and show essential differences in detail. The drum beaters are grooved longitudinally, and in the smaller machine have the section shown in Fig. 17, Plate 44; while in the larger machine they have the heavier section shown in Fig. 18, each beater here weighing 22 lbs. Eight beaters are fixed on each drum B, Fig. 14, and the three drum-heads are flanged steel discs. The drum is of considerable weight, which may be considered an advantage, especially when the feeding is irregularly done. The concave B^1 is built up in the same way as those previously described, the adjustments being similarly effected at the bottom and middle, and at the top by the adjustable crank-arm and connecting-rod C shown in Fig. 14. The jog board D under the shakers, and the riddle E, the lower shoe G, and the upper second dressing shoe L, all receive their reciprocating motion from the crank T, situated in this case in the front part of the machine. The boards composing the riddle E are only two in number, instead of four or five in the machines previously described; two pairs of interchangeable wood riddles go with each machine, the one with $\frac{1}{2}$ in., the other with $\frac{5}{8}$ in. holes. The fine riddle is generally used for wheat, but very often one board of each is used as a set. The holes are bored through the wood at a small angle, with $1\frac{3}{8}$ in. longitudinal pitch. The transverse section, Fig. 15, is taken through the upper second dressing shoe L, and through the lower shoe G; the arrangement of both first and second dressing sieves is thus shown in Figs. 14 and 15. The whole of the products of thrashing, after the removal of the cavings on the riddles, pass to the chaff sieve G in the lower shoe. The grain and seeds pass through the sieve on to the board or plate below it, Fig. 15; while the chobs fall over the end of the sieve G to the chob-sieve and the spout shown below it, and the chaff is blown out beyond. The grain and seeds slide down the board below G, and pass thence to the bottom of the elevator box J, Fig. 14, from which they are carried up by the elevator, and delivered into the awner K; or if awning is not necessary, then direct into the upper dressing shoe L.

We now come to a special feature in this machine. Instead of the two separate fans to supply blast for the first and second dressings, as in the machines already described, Messrs. Garrett use a single fan, which is placed on one end of the drum spindle at H, Figs. 15 and 16. This arrangement saves two spindles, straps, and sets of bearings; indeed there are machines made in which three sets of fans are employed. The blast is taken off at two points from the fan case, through tangential trunks T, Fig. 16, leading respectively to the first and second dressing apparatus. The blast is controlled and made uniform by means of wood slides within the trunks, and the pressure is adjusted to that desired by throttle-valves, also within the trunks. One of these is shown at T^1, Fig. 15, and the lever for controlling it in Fig. 14. These levers are actuated by screwed rods and hand wheels, situated at the points of delivery of the chaff. The attendant can thus adjust the pressure of the blast while he is examining the chaff to see whether anything else is brought over with it; and he can at once see the result of his adjustment. The dust and chaff separated from the grain in the second dressing shoe are blown over and delivered down the dust spout R, Fig. 15.

The corn elevator J, Figs. 14 and 15, is placed within the frame of the machine, the cups being of the form shown in Figs. 19 and 27, which somewhat differs from that in Fig. 24. The cups are attached to the leather belt by copper rivets. The screen O, Figs. 14 and 15, is of the cylindrical revolving form of Messrs. Penney and Co. of Lincoln. The machines of Messrs. Ransomes Head and Jefferies are carried in front on wood beds resting upon a large cast-iron ball-and-socket locking plate, which in turn rests upon a wooden axle-tree on the axle, as shown in Figs. 2 and 4, Plates 38 and 39. The machine of Messrs. Clayton and Shuttleworth is carried upon a wood bed and frame-work with wrought-iron locking plates, as shown in Fig. 9, Plate 41. Messrs. Garrett and Sons' machine is carried at the hinder end upon two flanged and dished steel plates, as shown in Fig. 14, Plate 43, and Figs. 20 to 22, Plate 45 : the upper plate is pressed to form the upper half of the locking plate or gear, and is prolonged upwards at each side and attached to the lower member of the machine frame; the lower plate is fixed to the axle. The

front end of this machine is also supported upon a flanged and dished steel plate, fitted and bolted to the axle, with a thin intervening strip of wood, as shown in Figs. 14 and 15. By this arrangement the road wheels are brought directly under the main cills or bottom members of the frame, as seen in Fig. 15, Plate 44, without specially increasing the height of the machine from the ground. When in work the machine is fixed, or made rigid, upon its wheels by driving wedges in between the frame and the tops of the wheels, which expedient, together with the usual chocks under the wheels, makes the machine stand very steady. The steel carriage-frames, as above described, are at the same time very light and very durable.

Davey Paxman and Co.'s Machine, Figs. 25, and 28 to 30, Plates 46 and 47.—Here again are some slight modifications in arrangement. The drum-heads are of cast iron with intermediate wrought-iron rings, the heads being of sufficient weight to secure the necessary strength, while the use of cast iron enables the makers to provide snugs or supports at the backs of the wooden beater-beds. The beaters are those known as Gouchers. The drum bearings and the supports and adjusting screws of the concave are in this machine all carried in large cast-iron panels A, Fig. 30, at each side of the machine. These parts are thus firmly held and fixed, while the panel at each side forms itself a good support to the wood framing. A loose piece L in the top of the frame on each side, and in each panel above the drum bearing, facilitates the removal of the drum, when necessary, for balancing or for repairs. All the bearings in the machine are carried in spherical cups, so that the shrinkages and settlements due to climate and strains have little or no effect upon the journals. The four shakers C, Fig. 28, are carried upon two crank-shafts S, the four dips upon each shaft being set at 90 degrees apart. The upper parts of the shakers C, instead of being covered with cross ribs of wood, are covered with perforated iron plates.

It may be useful to follow the relative positions of the four shaker boxes through one revolution of the shaker cranks, in order to give an idea of the extent to which the straw is shaken. In Fig. 23, Plate 45, is shown at A, for all the machines described, the position of the four

boxes, with the left-hand dip of the crank in its uppermost position; the horizontal dotted line in this and the three following figures representing the centre line of the crank-shaft. At B is shown the position of the shaker boxes and the straw above them, when the shaft has made one fourth of a revolution. In this quarter revolution it will be seen that the two end boxes have entirely changed their positions. At C is shown the position of the boxes when a second quarter revolution of the shaft has been made. Here again it is seen that from a transverse inclination in one direction the straw is tipped to a steeper one in the other direction: only to be reversed again to an equal extent when the third quarter revolution of the crank has been made, as at D. As the speed of the shaker cranks in the machines described varies from 150 to 195 revolutions per minute, it will be seen that these changes of position are very rapid. The double-crank arrangement of shakers is considered by many to be more effective than the single-crank arrangement; but both systems are adopted by eminent makers.

P. and H. P. Gibbons' Machine.—Figs. 26, and 31 to 33, Plates 48 to 50, illustrate this machine. A special feature is an exhaust fan at N, Fig. 31, for drawing the chaff from the lower shoe G and blowing it upwards into the chaff box F above, whence it drops from spouts into bags or baskets. Single-crank shakers C C are employed, similar to those already described; and the slight differences in arrangement of the first and second blast fans H and H^2, the lower dressing shoe G, and the upper finishing dressing shoe L, are sufficiently clearly shown in the drawings. It should be remarked however that by the arrangement of the second dressing shoe L in this machine, and of the blast fan H^2 connected with it, the small chobs and whitecoats, removed in the awner K and separated in the sieves L, are blown down under the drum B, Fig. 32, and thence to the riddles E. A similar arrangement is also adopted for this purpose in the other machines described, but it is not shown in all the drawings. Fig. 32 also shows the machine fitted with self-feeding attachment A, by which the feeding is more regularly performed than by hand. This apparatus covers the drum B, and makes a drum-guard unnecessary.

It consists essentially of shaker frames A, worked by a four-throw crank-shaft, the upper part of the shaker frames being provided with notched boards set upright upon the flat boarded covering of the frame. Besides the movement of these shakers, tines T, reciprocating through a small arc, direct the corn into the drum, as shown in Fig. 32.

Robey's Machine.—A machine presenting several features worthy of special note is made by Messrs. Robey and Co., of Lincoln, Fig. 36, Plate 51. The frame is made of angle iron, riveted together, as shown in the drawing. The frame thus made is not only light, but it is also very strong, and has the special advantage that it is not affected by heat or moisture. The shrinkage to which wood is subject, especially in the high temperatures of the summers in most foreign countries to which English machinery is sent, often causes considerable inconvenience; and, where care is not taken to keep all bolts and nuts well screwed up, most of the bearings, and especially the drum bearings, are liable to heating and excessive wear. These difficulties are overcome with the iron frame; but it has the disadvantage that it is sometimes difficult of repair after accidents, such as occur from collision with field gate-posts, or (as is far from unknown in some countries) from the machine getting turned over on bad roads. The shakers C are also arranged upon a system which differs from any of those previously described. They are worked by a single crank-shaft S at about a quarter of their length from the upper or delivery end. At the end near the drum B they are carried upon long stirrup irons, jointed to hanging bars F, which are pivoted behind the top part of the concave B^1; one of these hanging bars is also utilised for conveying motion to the second dressing shoe L. The shakers thus mounted have, it will be seen, but a small range of vertical motion near the drum, the range increasing towards, and being greatest at, their upper ends: so that the straw travels slowly when first leaving the drum, and while full of corn, cavings, chaff &c., but the rate of travel and the amount of shaking increase as those materials are shaken out.

Another feature of this machine is that the reciprocating jog-board under the shakers, in other machines, is here replaced by

a fixed board D, over which travel backwards a number of wooden cross-bars, attached to a pair of chains running over grooved sheaves. By these travelling bars the whole of the material shaken out of the straw is delivered on to the upper end of the wood riddle E. The advantage of this arrangement is that the upper shoe is reduced in weight by the weight of the usual jog board D. This reduction is important, in view of the rapidity with which the whole of the upper shoe oscillates. The reduction in weight moreover equalises the weights of the upper and lower shoes, and, as these reciprocate always in opposite directions, any vibration of the machine is avoided. Against the power gained by reducing the weight of the upper shoe must however be set that necessary to drive the endless chains and wood cross-bars upon the board D. Again, the upper and lower shoes are here driven by means of eccentrics T, instead of cranks. After the dressing in the lower shoe the grain is elevated as in other machines, and delivered either into the awner K, or into the creeper R if no awning is necessary. The direction of the grain into either the one or the other of these is effected by means of a plate P, hinged at its bottom edge, and taking either of the positions shown full and dotted, the end of the plate just clearing the tips of the elevator cups. The creeper R carries the grain across the machine, and delivers it into a spout, from which it is either passed through the rotary screen O, or led direct to the sacking spouts.

Amongst other makers of machines which have earned a high reputation are Messrs. Nalder and Nalder of Wantage, and Messrs. E. R. and F. Turner of Ipswich, from whom the Author has received very full information, part of which will be utilised farther on. But to describe their machines, and also those of Messrs. R. Hornsby and Sons, Messrs. Ruston Proctor and Co., Messrs. Marshall Sons and Co., and others, would extend the paper to too great a length.

General Constants for Thrashing Machines.

From the descriptions which have now been given, it will have been seen that among the chief elements of a thrashing machine the drum and concave stand first. In the large fixed machines

which were made in the early part of this century, and even some time after the construction of the portable steam thrashing machine in 1842, both drum and concave were fitted with short pegs, or short blunt knives, which passed between each other; but with these the straw was very much broken and cut up, while the thrashing was no better than with the beaters and concaves now generally used, which injure the straw very little when the machine is properly fed. With the old peg-and-beater drums, as they were called, a comparatively low velocity was sufficient; but the high velocity used for the modern machines here described is now easily obtained, and a greater quantity of work can be done with the modern drum. It is moreover necessary, especially for farms near large towns, that the straw should be damaged as little as possible. The average velocity of the tips of drum-beaters in English machines is nearly 6000 feet per minute. It might be thought that with this velocity a plain beater bar would thrash as efficiently as the ribbed beater; but this does not seem to be the case, although plain angle and other bars are used for machines of small power.

Inasmuch as all other moving parts of a thrashing machine receive their motion from the drum spindle, a high velocity of drum is effective in maintaining uniform motion of those parts; otherwise it might be asked whether a larger diameter of drum or a larger number of beaters, with a lower velocity, might not be advantageously employed. For maintaining a uniform velocity of the secondary parts, a considerable weight of drum is sometimes considered essential: thus the six-beater drum of Messrs. Ransomes weighs rather more than $3\frac{1}{2}$ cwt., while the eight-beater drums of most other makers weigh over $2\frac{1}{2}$ cwt.

As all parts of the machine receive their motion from the drum spindle, and as all the material received by these parts must first pass through the drum, and depends in quantity upon the drum capacity, it will be seen that, except for special cases, there must be a direct relation not only between the circumferential area of the drum and the area of the other moving parts, but also between the circumferential velocity of the drum and the velocities of the other parts; and hence also between the product of area multiplied by

velocity in the drum and in the other moving parts. These relations may be expressed as constants, which will be applicable in all but special cases. A set of such constants might be given for each different machine; but the Author will here deal only with the constants which are a mean of the constants found for the different machines (including those of Messrs. Nalder and Nalder and of Messrs. E. R. and F. Turner) referred to in this paper.

Constant for Shakers.—All the shakers shown in the drawings are of the reciprocating form, receiving their motion from one or from two cranks. In the latter case any part of each shaker section describes a circle, the direction of motion always being such that in the upper part of the circular path it is moving away from the drum, and thus carries the straw upwards and forwards. For many years Messrs. Ransomes made a rotary shaker, Fig. 6, Plate 39, consisting of a number of triangular wooden cross-bars, which revolved in the direction of the arrows, turning in stationary bearings at each end; they were provided with small tines at each apex of the triangles. In falling from apex to side of each of these bars the straw received a shaking, and was carried forward, partly by the help of the tines, which were curved backward. These shakers required less power to do their work than those shown in the machines described. The shaking was not however found to be always sufficient when the straw was damp; and when very damp, it often wound round the triangular bars of the shaker, and thus caused the stoppage of the machine. The form of shaker shown in Fig. 2, Plate 38, has for this reason been adopted by the firm. The employment of a single crank and rocking bearers, or of two cranks and no rockers, seems to be entirely a matter of individual preference. When two cranks are employed, the vertical range of movement in each shaker section is the same throughout its entire length; but when one crank only is used, a greater range of vertical movement is given to the free end of each section, while that of the end attached to the rocker or vibrating arm is very small. The mean range of vertical movement for the whole length of any shaker section, whether with one or two cranks, is thus about the same. Generally speaking the number of

feet moved through vertically in a given time, by that part of the shaker section which is immediately over the crank, is somewhat greater with double-crank shakers than with single-crank shakers; but the mean total movement is as great in the single-crank shaker as in the other, depending as it does upon the distance at which the crank is placed from the middle point of the shaker section, as well as upon the throw and the speed of revolution of the crank. The width of shakers is usually very nearly the same as the length of the drum, and their length is about double the length of the drum.

A considerable stroke is necessary for a shaker, in order that the shaking of the straw may be sufficiently violent; a very short stroke, even with a high velocity, not being as efficient as a similar total motion per unit of time with a longer stroke. In comparing the velocity of movement of the shakers with that of the drum periphery, it is therefore not sufficient to take the total mean vertical movement (or feet moved through per unit of time) by the shaker sections, but it is necessary to assume a minimum vertical range. The throw of the crank is thus to a certain extent fixed, and especially is it so with the double-crank shaker. Comparing a number of double-crank machines, the mean stroke is found to be 4·6 in., with a mean of 348·4 strokes or 174·2 revolutions per minute; giving a vertical speed of 133·5 ft. per min., or 0·0222 of the drum surface-speed, which is about 6000 ft. per min. Although with single-crank shakers the range of vertical movement at the free ends of the shaker sections may be greater than the throw of the crank, there is not much difference in the throw used. An average stroke is 4·25 in., with 345 strokes per minute, giving a vertical speed at the crank of 122·2 ft. per min., or 0·0203 of the drum surface-speed.

A special case is presented by the shakers now employed by Messrs. E. R. & F. Turner, the object of which is to secure greater range of motion in the shaker sections, with a single crank. This is effected by making each section in two parts jointed at the crank, the longitudinal frame pieces of each section being four instead of two, and the movement being like that of a pair of scissors, placed, with one handle and one blade nearly level, upon cross pieces suspended by hangers, and pivoted upon a crank-pin. A somewhat lower speed

of revolution may be possible with this shaker; but the crank must have a throw fully equal to those already referred to.

With a given throw of crank it may thus be taken that the total mean vertical speed of any shaker section will be given, according to the best English practice, by multiplying the drum surface-speed by the mean of the above coefficients, or by 0·0213. Were it not that the length of a thrashing machine is determined by the necessary length and arrangement of other parts, the shakers might be shortened, and the same amount of shaking given by increasing the range and velocity of the shaker sections at the delivery end.

Constant for Caving Riddles.—It is very important in machines for all countries that a sufficient area of riddle surface should be given. Too large an area is not likely to be given, because the length of the caving riddle is one principal element in determining the length of the machine, and it is also desirable to keep down the weight of the upper first-dressing shoe, which is always a heavy reciprocating part. The necessary area may be determined by reference to the developed surface of the drum: the term "developed" being here employed to express the product of the circumferential area and velocity in feet per minute of the drum, and similarly also the product of the area and velocity of the sieves. In the case of the machines described the mean developed surface of the caving riddle is 2446·6 ft. per min., and the coefficient in terms of the developed surface of the drum is 0·09374. But, as a large area of riddle with a short stroke is more likely to be efficient than a small area with a long stroke, the best coefficient for riddle area will perhaps be that which expresses the actual area in terms of the developed drum surface. The coefficient expressing this is 0·000802, the actual mean area of the riddle being 21·467 sq. ft. The effective area will of course be dependent upon the pitch of the holes. This ranges from 1 in. to $1\frac{1}{2}$ in. transversely, and from $1\frac{1}{8}$ in. to $1\frac{3}{4}$ in. longitudinally, the holes being in almost all cases in zigzag transverse lines. The mean speed of reciprocation of the riddles in eight machines is 114·54 ft. per minute; and the corresponding coefficient, expressing the ratio of riddle speed to drum surface-

speed, is 0·01909. Omitting two machines in which the velocity is considerably less, and one machine in which the velocity is much higher than in the others, this coefficient becomes 0·018869.

Constant for Lower-Shoe Sieves.—The first of these is the chaff sieve, which is usually of sheet-iron perforated with round holes $\frac{3}{4}$ in. in diameter. This sieve is so placed as to receive a blast, adjustable as to intensity, upon its under surface. The chaff is thus blown away over the end of the sieve, while the grain and heavier particles fall through to the first dressing sieve, or on to an inclined jog-board, and thence to the first dressing sieve. There is generally however some lighter grain, or some single grains to which pieces of the ear adhere. The specific gravity of these is sufficiently low to permit their being carried some distance with the chaff; and in order to prevent their being carried away altogether, the narrow board Z, Fig. 2, Plate 38, adjustable as to height and inclination, is placed near the end of the chaff sieve G. This board, as well as the blast, has to be so adjusted that all grains containing chaff and chobs may be just caught on the board, and may be delivered thence into the chob spout V; whence they fall into baskets and are again passed through the drum. The grain sieves, for which grooves in the shoe are provided, are from two to four in number, and vary in size of mesh from $\frac{3}{16}$ to $\frac{5}{8}$ in., according as they deal with seeds smaller than wheat, with wheat, or with barley and oats. The necessary area of each of these sieves may again be taken as a function of the developed drum surface, and the velocity of their reciprocation as a function of the drum surface-velocity. The mean area of these lower-shoe sieves in eight machines is 6·091 sq. ft., the mean developed area is 722·55 sq. ft. per min., and the mean velocity of reciprocation is 115·7 ft. per min.. There is considerable variation in these areas and speeds; but the above mean values coincide closely with the dimensions employed by two of the largest makers. The coefficient for the actual area of the sieves, in terms of the developed drum surface, is 0·000262; while the coefficient for developed sieve area is 0·02647. The relation between the velocity of reciprocation of the sieves and the drum surface-velocity is expressed by the coefficient 0·019285.

Constant for Second-Dressing Shoe Sieves.—The sieves of the second-dressing shoe L, Plates 38 and 39, are also under the command of a fan blast from a small second fan, in all machines except that of Messrs. Garrett. This blast blows away the chaff, or white coats and dust, removed by the awner; the arrangement of the blast-opening with relation to these sieves usually being such that a third blowing is given to the grain, as it leaves the last sieves. Grooves are provided for four sieves, and usually at least three sieves are used at one time. Some of these are of woven wire and some of perforated plate, a sieve with parallel wires being used for oats. The average area of sieve, in seven machines, is 2·867 sq. ft.; but in two of these the area is considerably larger, while the developed area is also larger. In these cases it is true that the first-dressing sieve area is also large; but the large area of the second-dressing sieves is probably provided in consequence of only two first-dressing sieves being here used, instead of three or four. It may however be noted that by a few makers the sieve areas are made sufficient to suit a wide range of requirements; while other makers modify the sieve areas according to the known requirements of the district in which the machine is to be used. The few makers referred to send the same machine to most countries from which they have orders; but this can only be done by making some parts much larger than is necessary for some purchasers. Expressing the second-dressing sieve areas in the same terms as before, the coefficient for the actual area is 0·0001065, while that for the developed area is 0·01063. The mean velocity of reciprocation is 100·09 ft. per min.; and the relation between this and the mean drum surface-speed is given by the constant 0·01668.

Fans, First-blast. The mean width of the first-blast fan, in seven machines, is 35·8 in., the mean diameter 21·5 in., and mean number of revolutions per minute 582·5. The quantity of air delivered by this, and by the second-blast fan, may be expressed in terms of the developed surface of the drum.

Fans, Second-blast. The mean width of these fans is 7·707 in.,

and the mean diameter 17·33 in.; in each case leaving out of account one unexplained exceptional size. The mean number of revolutions per minute is 695·33.

Screens.—Most of the screens employed are of Messrs. Penney's design, and all are adjustable in inclination. The mean diameter employed is 16·72 in., and the revolutions per minute 39. The largest diameter is 18 in., running at 40 to 50 revolutions per minute; this is in what may be termed the heavy class of machines.

It may here be noticed that the machines under trial at the Cardiff meeting of the Royal Agricultural Society in 1872, having drums 4 ft. 6 in. long, required on an average about 11 HP. to work them, when thrashing one ton of wheat in the sheaf in from fifteen to twenty minutes. The power required to work them empty ranged from 52 to 77 per cent. of that necessary to work them full. The heavy reciprocating parts, hanging upon non-synchronous pendulum rods, consumed a great quantity of power: it has been estimated that, of the whole power consumed, the drum takes 40 per cent., the shakers and caving riddle, with the other parts of the upper first-dressing shoe, 40 per cent., and the remaining parts of the machine 20 per cent.

This paper has already extended to such length that many questions relating to the construction and working of thrashing machines must remain unnoticed. Attachments—including the straw-chopping drums of Messrs. Ransome and of others, Messrs. Nalder's attached straw elevator, &c.—as well as machines to be worked by horses, and machines of various special classes, must also be reserved for some future occasion. In the Appendix is given however a description of the forms of drum guard used by the makers here referred to. To these gentlemen the writer wishes here to express his indebtedness, for the readiness and courtesy with which they have assisted him by giving every information requisite for the preparation of this paper.

APPENDIX.—DRUM GUARDS.

In August 1879 an Act came into force, which had for its object the prevention of accidents on thrashing machines. This Act made it compulsory to protect those engaged in working thrashing machines from falling into the drum-mouth, by providing a guard which would cover the mouth or the drum, as soon as any pressure not necessary for working the machine was brought upon the feed board, or upon a hood opposite to it. Previous to this, in 1874, the Royal Agricultural Society had offered prizes for the most efficient drum guard, and in 1875 about a dozen guards were entered for trial. Since that time considerable modifications have been made in the different guards. Some of the principal forms, as fitted to the machines here described, are shown in the drawings. It has seldom or never happened that the feeder has met with an accident by falling into the drum-mouth when in the feeding box; but those engaged in attendance upon the feeder, on the platform of the machine, have sometimes been killed in this way. Such accidents have most frequently happened in sweeping the loose corn into the drum, when the thrashing is nearly finished; or else from attendants walking about on the platform when the feeder was not in the box. By some makers it has therefore been held that a simple hood over the drum-mouth, to be closed by the feeder when he stops work, is a sufficient protection.

The guard attached to the machines made for this country by Messrs. Ransomes Head and Jefferies is shown in Plate 52, Figs. 37 and 38, which show the drum-mouth as open, and as closed by the guard flap. This guard is so constructed that it is almost impossible for anyone to fall into the drum B. A self-acting flap or shutter F, which when down completely closes the mouth of the drum, is so arranged that when open it does not interfere with feeding the machine, but will drop instantly and close the drum-mouth if anyone falls upon

either the hood H or the feed-board A. Sweepings can be swept into the drum as usual. The flap F is hinged at its lower edge, and is kept up, so as to leave the mouth of the drum open, by a hook C on the inside of the hood, which engages a projection on the upper part of the flap. The feed-board A is connected with the hood H by a lever centred at E and by the connecting-rod D. If anyone falls on to the hood H, or on to the feed-board A, the hook is depressed, and this at once liberates the flap F, which closes instantly, as shown in Fig. 38. A piece of board can be removed from the platform at the back of the hood, and this allows the hood to be set back, thus making the mouth wider, if required. The flap is made in two pieces, which slide one over the other, and are provided with set-screws to set them to the required width. There is a second hole G in the end of the lever E, for receiving the lower end of the connecting-rod D when the mouth is set wider. The range of motion in either hood or feed-board, necessary to liberate the flap, is very small; and anyone stumbling, even at the end of the drum-mouth, could not fall into the mouth without knocking or pressing either hood or flap sufficiently to liberate the flap.

The arrangement of guard used by Messrs. Clayton and Shuttleworth is shown in Plate 52, Figs. 39 and 40. The hood H is pivoted in bearings C, the caps of which are held down by a stud at one end, while the other end projects and rests upon a short spiral spring, against the resistance of which the nut of the stud is screwed down. The caps thus hold the pivots with a frictional grip, the amount of which is determined by the pressure put on the springs. This grip is made sufficient to hold the hood up under ordinary working conditions; but any extraordinary pressure, either upon the hood or upon the feed-board A (which is connected with it by a pair of flat bar connectors), causes the feed-board to tilt upon its pivots, and the hood to fall and cover the drum-mouth. For this purpose the feed-board pivots are prolonged through their bearings to the outside of the machine, and there carry short levers L L, Fig. 40; and the boards G G, forming that part of the platform of the machine which is beyond the ends of the drum-mouth, are hinged at their outer edges, and at the inner edges rest upon these levers. Any pressure

upon these boards consequently tilts the feed-board A, and the drum-mouth is thus completely protected.

Messrs. Richard Garrett and Sons are of the opinion shared by many, that there is no danger of accident so long as the feeder is in his place; and they therefore make a guard, Fig. 14, Plate 43, which always covers the drum so long as there is no one in the feeding box A. The hood H is pivoted a short distance above the platform, and a pair of short levers extend below the bottom of the hood at either end. To these are attached cords or chains running over small sheaves, and connected at their other ends to the board A forming the bottom of the feeding box. This board is pivoted at its front edge as shown, and when the feeder is absent it is held up (as shown dotted) in an inclined position by the weight of the hood acting on the connecting cord; but the feeder's weight depresses this board, and the hood is thus held up while he is in the box.

The guard employed by Messrs. Davey Paxman and Co. consists simply of a hood H held up in position for thrashing by a large box door-spring S fastened to the upper part of the drum-mouth frame, and bearing against the centre of the underside of the hood, as in Plate 47, Fig. 30.

The drum guard shown in Plate 50, Figs. 34 and 35, is that used by Messrs. Gibbons, when their automatic feeder is not attached. It is shown open in Fig. 34, and closed in Fig. 35. The feed-board A is so pivoted that the upper part bends downwards into the position shown in Fig. 35, when pressed upon more heavily than is usual in feeding. This at the same time raises the lower part of the feed-board, which is in the drum-mouth, and by means of the connecting links or rods L L lowers the upper part of the hood H. The hood being pivoted at about its horizontal centre, its lower part, on being thus pushed backward, pulls up the board C, which is attached to it by a chain, so as to make it meet the lower edge of the feed-board. By this means the opening at O is so far closed as to exclude any large object, while the lower part of the drum-mouth is completely closed, as shown in Fig. 35. The feed-board A is also connected to a ratchet quadrant Q. When the board is depressed, this quadrant is carried round by it, and the board is held in the

new position by a spring bar, which takes into the ratchet-teeth. This spring must be lifted out of the teeth before the board can be released. The feed-board may be adjusted to act under any pressure deemed desirable as a limit, by attaching the link, which connects the board and quadrant, by any one of the four holes made in it for the purpose. The other board C closing the drum-mouth is also held up by a catch behind, as shown in Fig. 35; and the catch has to be released by a cord, in order to lower the board C and open the drum-mouth again, as in Fig. 34.

The guard used on the machine made by Messrs. Robey and Co. is arranged like Messrs. Garrett's, so that the drum-mouth is always closed when the feeder is absent; and for the same reasons. A hood is placed at the back of the drum-mouth, and a hinged board therein is connected by curved links to the bottom of the feed-box, which is also hinged. The depression of the bottom opens the hood.

There is one more drum guard to which attention should be drawn, namely that shown in Plate 52, Figs. 41 and 42, and made by Messrs. E. R. and F. Turner. The feed-board consists of two parts, an upper A, and a lower C, connected by end pieces and hinged to the top of the concave B^1. Pivoted to these end pieces is a double-armed lever L, the long arm of which rests upon a spring S, while the short arm, which is hooked at its end, engages with a link J, pivoted near its upper end and hinged to a board I. When accidental pressure is brought to bear on the feed-board A, the short arm of the lever L is raised, the link J is liberated, and the board I, suspended by the link J, immediately slips down by its own weight, and covers the drum-mouth, as shown in Fig. 42.

There are many other drum guards in use; but those described are sufficient to show the general construction of these somewhat important and ingenious safety-appliances.

Discussion on Thrashing Machines.

Mr. Beaumont exhibited a pair of dished steel locking plates with cross-bearer, as used by Messrs. Garrett and Sons; also specimens of beater-bars from Messrs. Garrett and Sons, and Messrs. Clayton and Shuttleworth. He also called attention to one of Goucher's beaters made of malleable cast-iron, kindly lent by Mr. A. Barclay; this was twisted up, as an illustration of the way in which that iron could be twisted about without breaking: although the beater was actually used in the straight form, in the same way as others. He also showed photographs of machines made by Messrs. Clayton and Shuttleworth. He observed that the limits imposed on the paper in reading had necessitated leaving out several points upon which discussion might perhaps have arisen. For instance, all these machines, as now used in England at least, were fitted with a guard over the drum, so that persons could not fall into the drum and be hurt, nor accidents take place after the thrashing was finished, when the men were sweeping the sweepings into the drum. These drum guards were described in the Appendix. He might also mention an apparatus by Messrs. Clayton and Shuttleworth for chopping the straw into short pieces, after it left the main drum and shakers, as fitted to machines intended for countries where straw was used for fodder. There were also many small machines driven by horses; and others with attachments, such as an elevator fixed to the front of the machine, to take the straw away from the shakers direct to the straw rick.

With respect to the coefficients which he had given in the paper, this was, he believed, the first time any attempt had been made of that kind; and further time and attention might be necessary for developing them fully, especially where some diversity of practice existed among makers: as, for instance, in the number of sieves that were in use at the same time.

Mr. Jeremiah Head said, if he troubled the meeting with any remarks, it was because he was one of the members of Council to whom

this paper had been referred, according to the ordinary custom, to be read over, before it was laid before the Institution. He must say that after reading it he felt it was a very valuable paper indeed, and one the preparation of which must have cost the author an immense deal of time and trouble. He also felt after reading it that he knew a great deal more about the inside of one of those mysterious-looking machines than he ever did before. As a boy he had had the run of a farm in an agricultural county, where at that time thrashing by the flail was still very much in vogue. The thrashing machine seemed to him to embody all the crude operations of the flail, and to add certain operations which could not formerly be done at all. All the corn was then of necessity brought into the barn, in order that it might be thrashed on the floor. After the flail, which answered to the drum of the machine, had been in operation for some time, the straw was removed with a pitchfork, leaving the grain, chaff, seed, &c., mixed together upon the floor. Next, all the wheat and chaff was put into a winnowing machine, where it was subjected to a process of fanning, similar to that in the thrashing machine. The corn was then supposed to be fit for the market, except in respect of sifting and screening, which, if done at all, was done by ordinary hand sieves. It was evident that this plan must have required an immense amount of manual labour. It also necessitated the bringing of all the corn into a central place, and the straw was stacked near at hand. This afforded great opportunities for those rickyard fires, by which offended labourers were able to revenge themselves in a very disastrous manner. But the thrashing machine, which did the whole of the operations needed, could be taken to the fields where the corn was produced; the corn could be thrashed there, and the straw need not be uselessly and dangerously concentrated in one place. He believed that many of the other operations, such as the screening, the separation of the seeds &c., were not done at all in the old times; and therefore the market value of the product must be very much improved by the machines.

He did not propose to attempt any criticism of the machines, but would ask Mr. Beaumont one or two questions on matters of detail. In the first place, he believed that at one time Messrs. Clayton and

Shuttleworth used to elevate the corn from the bottom of the machine to the top by a fan placed inside of a Jacob's ladder. Perhaps Mr. Beaumont would state why that had been abandoned, if it had been abandoned. In the next place they had heard that in some important parts of the machine iron or steel had been substituted for wood, notably in the case of Messrs. Garrett and Sons' fore carriage. He should like to know whether it was out of the question still further to extend the use of iron and steel in the machine. There seemed to be a very large quantity of wood in it, and wood was a perishable material; besides, in implements which were to be dragged about rough roads for a long time, it was difficult to fasten wood together so as to avoid shaking apart at the joints. Of course the question of lightness might be urged in reply to this. Inasmuch as the specific gravity of iron was about twelve times that of wood, a sheet of iron $\frac{1}{8}$ in. thick would equal in weight a plank of wood about $1\frac{1}{2}$ in. thick; and therefore, as 1 in. would be about the thickness of most parts of the machine, iron or steel only $\frac{1}{12}$ in. thick would have to be used in order to keep down to the same weight. Still, considering what progress had been made in recent years in the art of securing strength in thin sheets of iron or steel, by corrugating, or by stamping after the form of Mallet's buckled plates, it seemed not altogether out of reason to hope that a good many parts of the machine, such as the sides, might be made of steel sheets, say $\frac{1}{16}$ in. thick, in the form of panels.

Mr. W. E. Rich thought it might be well to remind members that they would find a great many valuable statistics of the performances of thrashing machines in the Journal of the Royal Agricultural Society for the year 1872 (p. 404), describing the trials of thrashing machines which took place at Cardiff. Some thirty machines by different makers were subjected to very crucial tests on a dynamometer, and statistics of the sizes of the machines were given, with the number of men employed upon them, the time they took to thrash out grain, whether wheat, barley, or oats, the way in which they did their work, the economy of power when thrashing the different materials, and the proportion of power taken to work each machine

empty compared with that taken when it was thrashing. The economical results were worked out for each machine, as had become usual with other agricultural machines of late years, in terms of the ft.-lbs. expended per pound of sheaf corn thrashed. The average figure was about 2500 ft.-lbs.; in other words, a sheaf of corn would have to be raised 2500 ft. to represent the power consumed in thrashing it.

In thrashing machines generally it was singular how unanimously makers had come to certain fixed dimensions for the diameter and length of drum, and for the sizes of many parts. Nearly all the machines sent to Cardiff had drums 4 ft. 6 in. long; one or two had drums 5 ft. long, but those were abnormal machines for foreign work. He thought most English makers were agreed in speeding their machines so that the driving belt from the engine should run at one uniform speed of 1884 ft. per min. He believed that figure was originally derived from instructions issued by the Royal Agricultural Society many years ago. At Cardiff there was one iron-framed machine, which was commented upon favourably by the judges; but he had not seen it reproduced many times since. There was one point in connection with thrashing machines which he had often noticed, namely the use of wood connecting-rods or links, for working the shakers and many other parts, instead of multiplying the number of bearings and bearing pins, which latter in the dust of thrashing would very soon wear out, and would all require lubrication. Most makers of thrashing machinery used a light thin lath of wood, generally straight-grained ash, with sufficient spring in it to allow the necessary amount of motion without any pins at the ends. He had sometimes thought there were other cases, in the practice of mechanical engineers, where a similar lath, whether of wood or of steel or iron, might be used with advantage.

The President asked Mr. Rich whether the diagonal feeding of the corn into the beater, which he believed was now usual, made the machines go lighter or heavier; in other words, what effect it had upon the horse-power required to work them, as given on p. 391.

Mr. Rich did not remember any statistics as to the influence of that condition on the economy of power. No doubt many workmen did lay the corn in diagonally, and some even threw it in almost parallel. The head of the grain fell forward directly it was released from the hand, and it was formerly thrown in almost perpendicularly to the length of the drum; now the feeding was done very much aslant, and when the straw was required for thatching, it was fed in parallel to the drum, as that mode of feeding did not break the straw so much. The number of drum-guards brought before the Royal Agricultural Society of late years was almost legion. They were now fitted to all machines in England, being required by law; but he thought the authorities of the Society recognised that there was still room for a good, simple, and effective drum-guard, which should not interfere with the feeder performing his work.

Mr. V. Pendred said Mr. Rich had spoken of the uniform dimensions of thrashing machines. He himself had made one in 1862 for a barn, with a drum 5 ft. 6 in. wide,—probably about as wide as any that had ever been made in England. There were a great many scientific points connected with the construction of thrashing machines, which might probably escape the attention of engineers who had not devoted special attention to the subject. There was a popular idea among many engineers that an agricultural machine was a rough, simple thing, that could be made by anybody; but when it was considered how thrashing machines had been worked up from very crude and simple arrangements to what they were now, he thought it might be justly said that the inventors of those machines were as good engineers and as clever schemers as had ever lived. For instance, if any engineer, not accustomed to thrashing work, were asked to drive a heavily-loaded shaft, with a strong pull on the belt, at 1300 revs. per min., and to keep it perfectly cool at the same time, he thought that engineer would insist on as firm a frame to put it on as he could possibly get. Yet thrashing machines ran at about that speed, and ran cool; and that often when their old wooden frames had been greatly shaken, and had become quite rickety. That result had been accomplished by very

careful adjustment and proportioning of the dimensions of the bearings, brasses, and shaft. Mr. Beaumont had referred to the use of cutters for chopping the straw as it came from the machine. These cutters were rollers. Knives set on a drum passed between little fixed studs; and in one instance which he had seen he had calculated that the drum was running at nearly 2000 revs. per min. That was a very high velocity to deal with and to keep the parts cool.

He believed more improvements would be made in thrashing machines, were it not that of late years they had had to be turned out at as low a price as possible. There were one or two points about thrashing machines which he thought were still open to considerable improvement, from a scientific point of view. In a great many machines very heavy reciprocating shoes were used; and in the case of Robey's machine, Fig. 36, Plate 51, an attempt had been made to reduce the weight of one of these shoes by putting in chain gear DD instead of the usual jog board, as described in the paper, p. 383. The hangers of these shoes were really a set of pendulums varying in length from 18 in. to 3 ft., and in some cases 4 ft. Further, to suit the exigencies of construction, one end of a shoe was often hung by a pair of pendulums 3 ft. long, while at the other end their length was something like 20 in. only. No attempt he believed had ever been made to make the time in which the shoe was swung coincide with that due to the pendulum length. The rate of oscillation was not synchronous with that due to the length of the hangers, acting as pendulums; and power was thus wasted. Some twelve or thirteen years ago an ore-separating machine had been brought out, in which the pendulum principle was carried out in a way that he imagined might be applied in thrashing machines. In the ore-separating machine, Plate 52, Fig. 43, a screen or reciprocating shoe A, some 12 or 13 ft. long and 20 or 30 in. wide, had a slight inclination longitudinally to the horizontal, and had a reciprocating motion imparted to it lengthways. There was a good deal of ironwork about the screen, so that it weighed probably $1\frac{1}{2}$ cwt. It could be driven at 180 oscillations per minute by a belt 1 in. wide, made of glove leather. A handle at the side was turned to make the screen oscillate; but a sensible resistance

was found, until it was turned at exactly the speed of oscillation which synchronised with the pendulum length. The screen had a range of motion of say 3 in. Now to get the speed required in the oscillating shoe of a thrashing machine the proper pendulum length would be only $2\frac{3}{4}$ to 3 in., so that evidently slings could not be used there; and it was exactly the same with the ore-separator. The difficulty was got over in that case as follows:—from a crank B a connecting-rod was attached to some point C in the screen, to give the reciprocating motion; and there were four wheels D D at the sides of the screen to carry it. Now suppose these wheels ran on a plane surface, backwards and forwards, with a range of 3 in., then there would be no pendulum action whatever. In order to get a pendulum action, each of these wheels was made to run on a curve E; and as the wheels rose at each end of the curve, the centre of the wheel passed through the same path which it would have described if attached to a pendulum of 2 or 3 in. length. That exact arrangement could not very well be carried out in thrashing machines, because of the accumulation of dust and chaff; but the thing could be easily done by making the wheels a fixture on the frame of the machine and fitting the curved paths on the sides of the oscillating shoe, thus hanging the shoe upon the wheels by means of the curves. He need not go into details of how this could be carried out; there would be no special difficulty about it.

The only other point to which he would allude was that of shaking. There was another question to be considered besides the length of crank throw mentioned on p. 387: namely the remarkable effect that could be produced in shaking corn by a blow. Some years ago he succeeded in producing perfect shaking with a shaker only 6 ft. long (little more than half the length of the shakers which were used at that time), by striking the corn from below by narrow laths rising up through fixed girds. He did not know whether that principle had since been carried out in practice, but he believed it was thus possible to make thrashing machines shorter than they were now made; and this would be of considerable importance.

Mr. Beaumont, in reply, said he believed Mr. Head was quite correct in stating that the number of screenings was less in the days when thrashing was done by hand; but since agricultural engineers had shown farmers that they could separate the grain into several different qualities, the number of separations and screenings had increased, in response to the farmers' demand, until now there were two or three for wheat, and sometimes more than that for barley. With reference to Mr. Head's question as to the fan-blast elevator, several firms had tried to use a cast-iron case containing a fan, to elevate the corn to the top of the machine; but he believed none of them had succeeded in producing one which did not break the corn more or less, especially the hard wheat of Hungary, South Russia, and Italy. A good many machines so fitted had been sent abroad to these countries nearly twenty years ago; and, although the elevator answered in other respects, it was often found absolutely necessary to take off the sides of the fan casing and cover them with leather, so as to prevent their breaking the grain. That he believed was the chief reason that their use was discontinued.

Another question raised by Mr. Head was as to the use of iron or steel in the machines. He thought it was quite possible that iron or steel might be used in more parts of the machines than at present; but at the same time there were many places where wood of considerable thickness was used, and where neither iron nor steel could be employed. Take for instance the riddles, of one of which a section was shown in Fig. 13, Plate 42; it would be seen that, if the riddle were made of thin iron or steel, the pieces of straw there shown, instead of being thrown back by the sides of the holes, and afterwards finding their way right over the caving riddle, would slip through the riddles at once, and in that way get down to the other smaller sieves, which were meant to deal only with the grain, seeds, and so on. Again, so long as the shakers had the form now used, iron or steel could not be economically employed; because not only was it necessary to have the surface at the top of each section such as shown at CC in Figs. 4 and 10, Plates 39 and 42, but the sides also must be of such depth that the straw could not slip through between the sections. With such dimensions for the sides and seed-carrying parts, as well as for

the top parts, the shakers, if in iron, would be perhaps double the weight of what they would be in wood. He thought however that in some machines it would be possible to use thin buckled plates for the sides of the machine, instead of boarding. The question of cost, to which Mr. Pendred had referred, would be one element which would determine the application of iron or steel instead of wood. For many parts of the machine he did not see that either metal would be cheaper or so cheap. Then again it should be remembered that thrashing machines went to all parts of the world, and were often used many miles away from a blacksmith's shop; and that wherever they went they were liable to accidents. If the chief parts of the machine were made of iron or steel, it would often be difficult to do the repairs that might be necessary; but when they were made of wood, almost any country wheelwright, or any attendant on the machine, could with a few bits of wood manage to repair it, so that it would go on.

Mr. Rich had referred to the tabulated results of the trials made at Cardiff by the Royal Agricultural Society. That information was very full as to the working of the machines; but it had been necessary to omit from the paper all reference to points concerned in the working of the machines, because they would have made it two or three times its present length. Mr. Rich had referred to the length of the drum, as being generally 4 ft. 6 in. It had been found that a 4 ft. 6 in. drum suited general requirements better than any other size; but shorter lengths, both for steam and horse-power, were made by all makers, principally for farmers who preferred having their own machines, rather than hiring. Larger machines had also been made, especially he believed for Russian proprietors; but he thought that nothing over 5 ft. drum-length was used even there. Mr. Rich had also referred to an iron-frame machine exhibited at Cardiff. That form of frame, he believed, had been used almost ever since by Messrs. Robey and Co., and was shown in Fig. 36, Plate 51. The hangers referred to by Mr. Rich were usually made of very tough thin strips of ash. Although the idea was not much used by English mechanical engineers, applications of it were frequently made by American machinists.

As to feeding the straw diagonally, he believed when the straw was wanted for thatching it was almost always thrown in parallel with the drum: otherwise the feeding should take place as far as possible along the whole length of the drum. The feeder took up a quantity of straw, and put some of it in at one end, and some at the other, and some towards the centre; otherwise the drum wore most in one part. As a rule the drums did wear more in the centre than at the end, because feeders did not take sufficient care in spreading the corn throughout the length.

Mr. Pendred had referred to the speed of the drums and the pull of the belt. He would only remark that the fact of the drum-spindles running cool was still further surprising when it was remembered that there were all the other parts of the machine—the shakers, the heavy riddles, and the reciprocating parts—all driven from the same spindle; and that there was also the continual presence of dust.

With regard to the length of the hangers as pendulums, he believed one or two makers had tried to use shorter hangers, but not so short as would be dictated by reference to the proper length of a pendulum for the number of oscillations per minute that were necessary for those parts. They oscillated about 200 times per minute, and it would be seen from this fact alone that the pendulum would necessarily be very short indeed.

The President asked if Mr. Beaumont could give any information as to the advantage of weighing the corn into sacks direct from the thrashing machine.

Mr. Beaumont said that was very seldom done at the thrashing machine. After the corn had gone to the barn, it was weighed by means of a weighing machine, sometimes placed in connection with a second dressing machine. The automatic weighing in such cases was usually effected simply by means of a little lever, connected with a vertical slide which opened or closed a spout on the top of an elevator attached to the machine; the slide was kept from falling and closing the spout by means of a little catch attached by a cord to

the weighing-machine scale. This scale, as it dropped, removed the catch, pulled the lever, and permitted the slide to fall and close the spout.

The President thought the members would agree with him that they ought to pass a cordial vote of thanks to Mr. Beaumont for his valuable paper. It was very liberal on the part of the manufacturers to supply so much information as they had given—information which was extremely valuable, and interesting to them as engineers and mechanics; and some of the points brought forward would probably set them thinking. The elastic wooden connections were no doubt very useful, because the fewer joints there were, in all the dust and dirt of such operations, the better; and no doubt the same device might be used with advantage in some other classes of machinery.

Fig. 1. *Section of Lap Joint.*

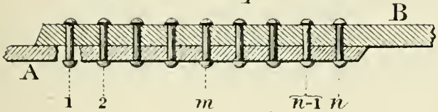


Fig. 3. *Plan of Lap Joint of uniform strength, 95 per cent. of solid plate.*

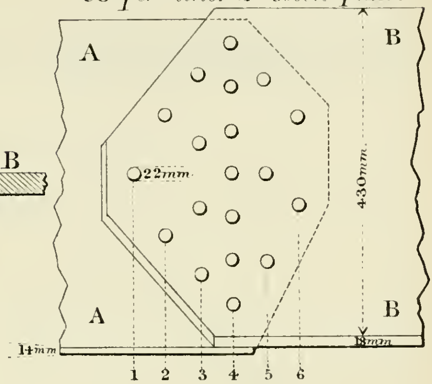


Fig. 2. *Modes of Rupture, tearing plate* B.

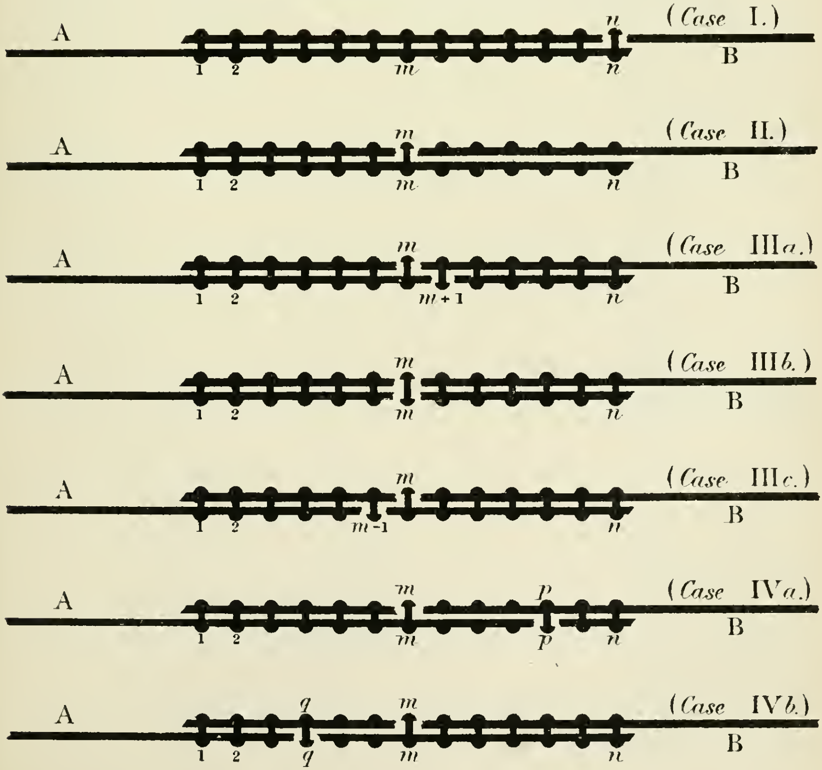


Fig. 4. *Butt Joint with one cover-plate.*

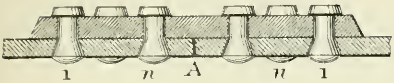
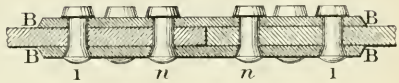


Fig. 5. *Butt Joint with two cover-plates.*



Reduction of Width.

Fig. 6.

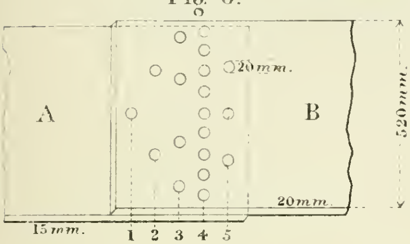


Fig. 7.

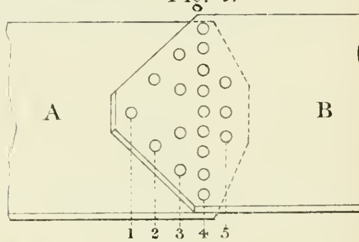


Fig. 8. *Butt Joint in Deck-plate.*

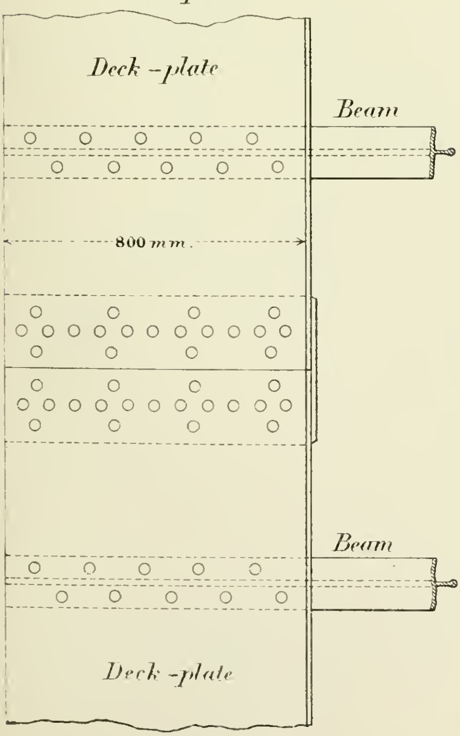
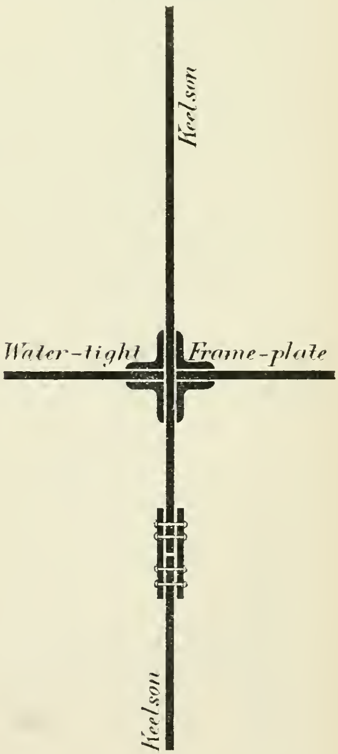


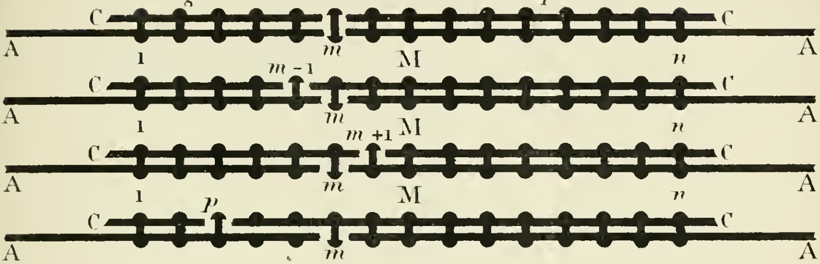
Fig. 9. *Butt Joint in Keelson.*



(Proceedings Inst. M.E. 1881.)

Riveting of Strengthening Plates.

Fig. 12. *Possible modes of Rupture.*



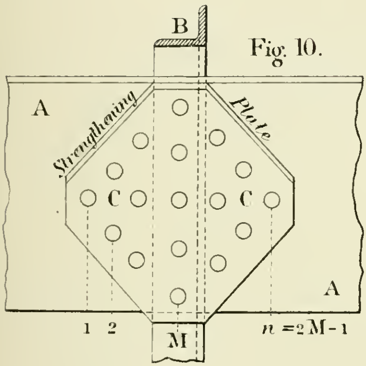


Fig. 10.

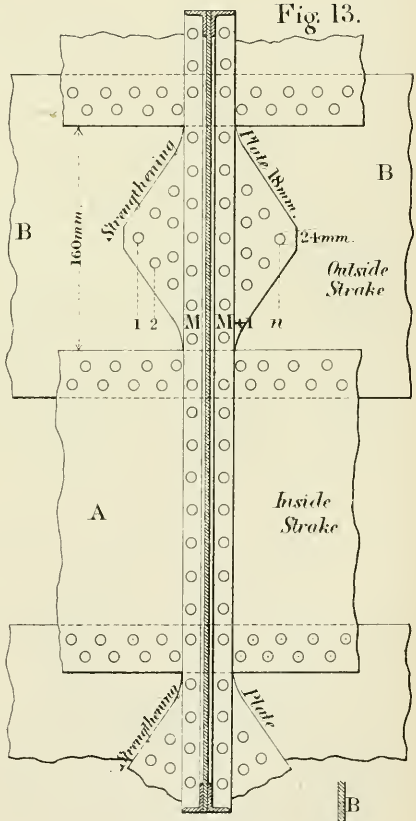


Fig. 13.

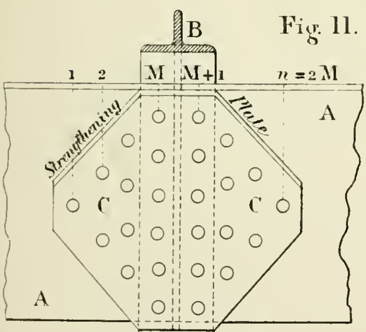


Fig. 11.

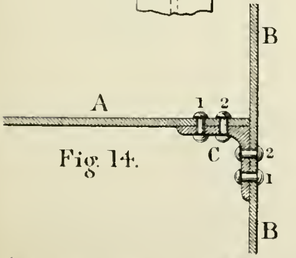


Fig. 14.

Angle-Iron Attachments.

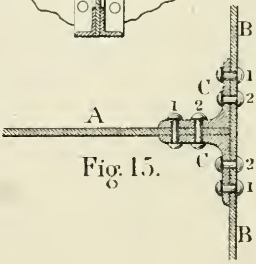
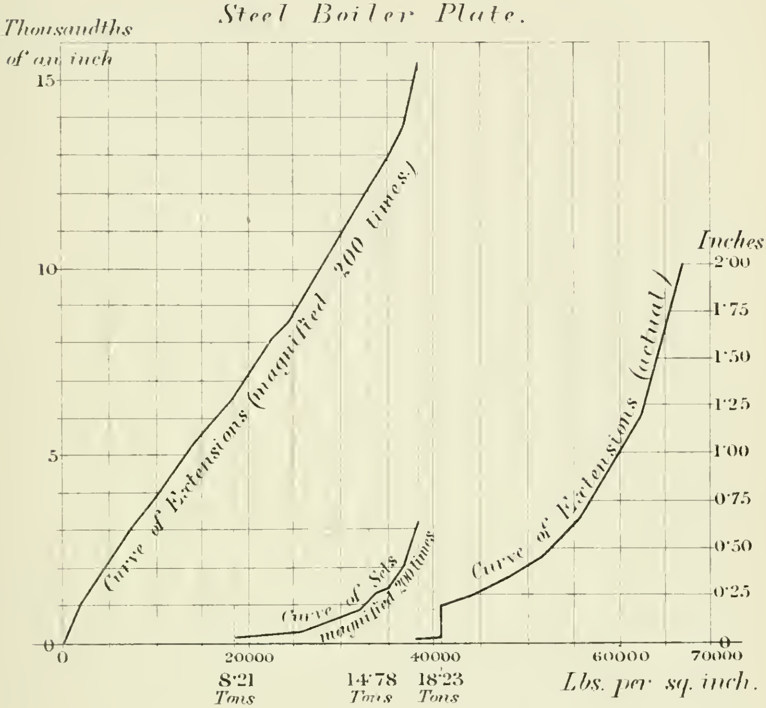


Fig. 15.

(Proceedings Inst. M. E. 1881.)

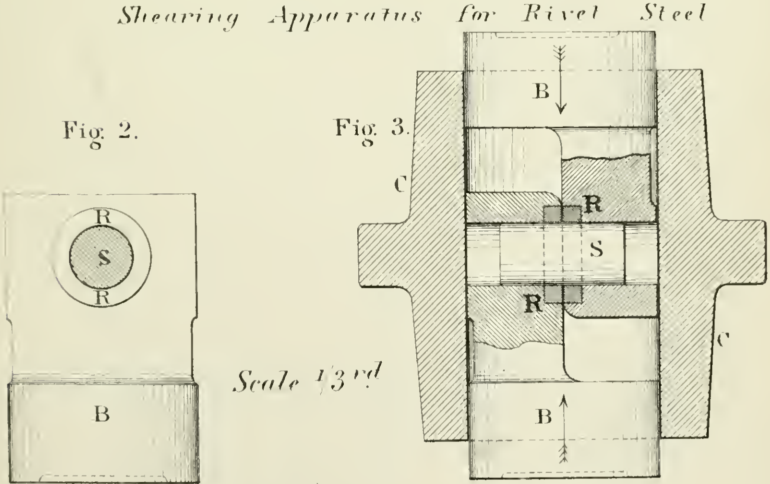
Fig. 1. *Diagram of Sets and of Extensions in 10 inches length of Test Strip 272–2. Fig. 3. Steel Boiler Plate.*



Shearing Apparatus for Rivet Steel

Fig. 2.

Fig. 3.



(Proceedings Inst. M. E. 1881.)

Steel Boiler Plate test strips. Half full size.

Fig. 4.

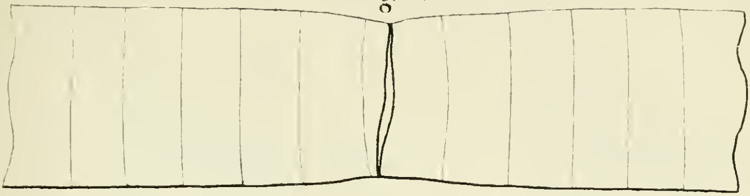


Fig. 5.

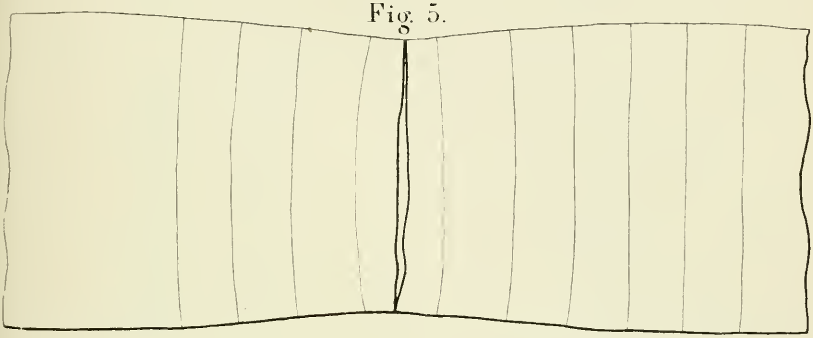


Fig. 6.

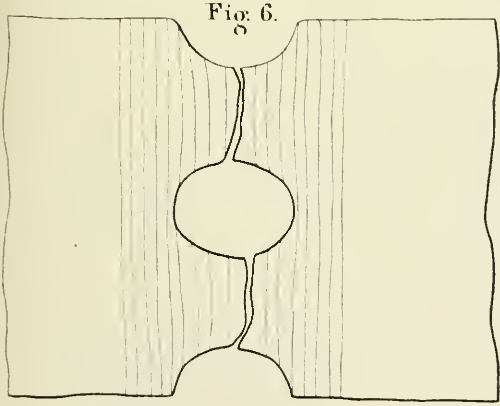
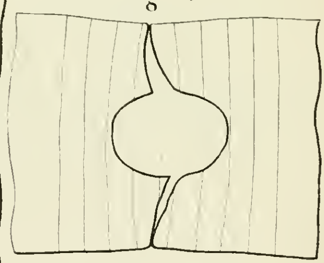


Fig. 7.



Tests by Manchester Steam Users' Association.

Fig. 8.

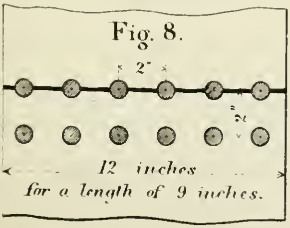
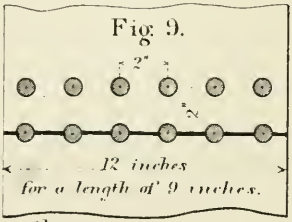


Fig. 9.



(Proceedings Inst. M. E. 1881.)

Scale 1/8th.

RIVETED JOINTS. *Plate 32*

Angle-Iron at front end of Locomotive Boiler.

Scale 1/4th.

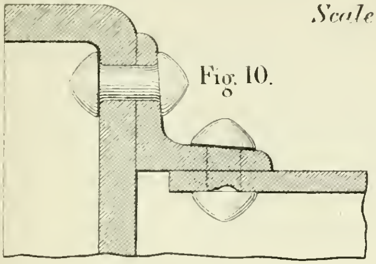


Fig. 10.

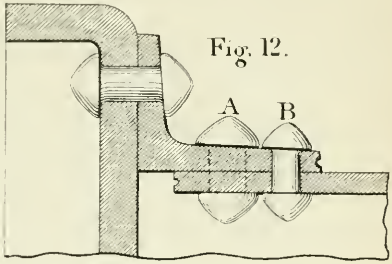


Fig. 12.

Fig. 11. *Inverted Plan.*

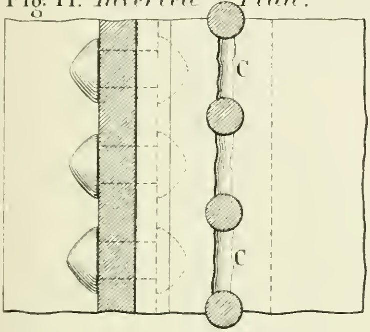
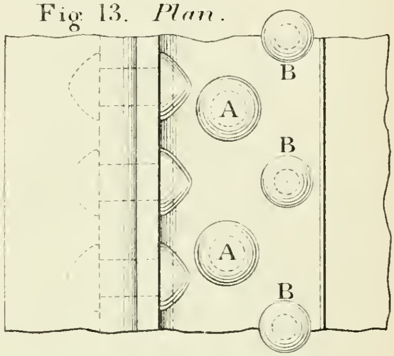


Fig. 13. *Plan.*



Caulking Tool.

Fig. 14.

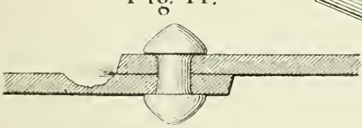


Fig. 15.

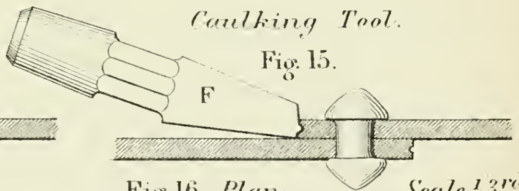
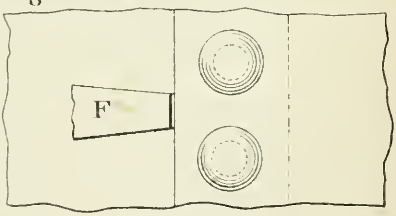


Fig. 16. *Plan.* *Scale 1/3rd.*



Punch and Bolster.

Fig. 17.

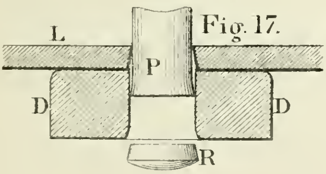


Fig. 18.

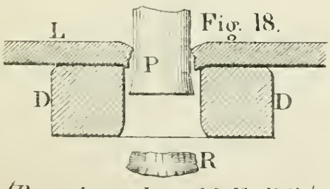
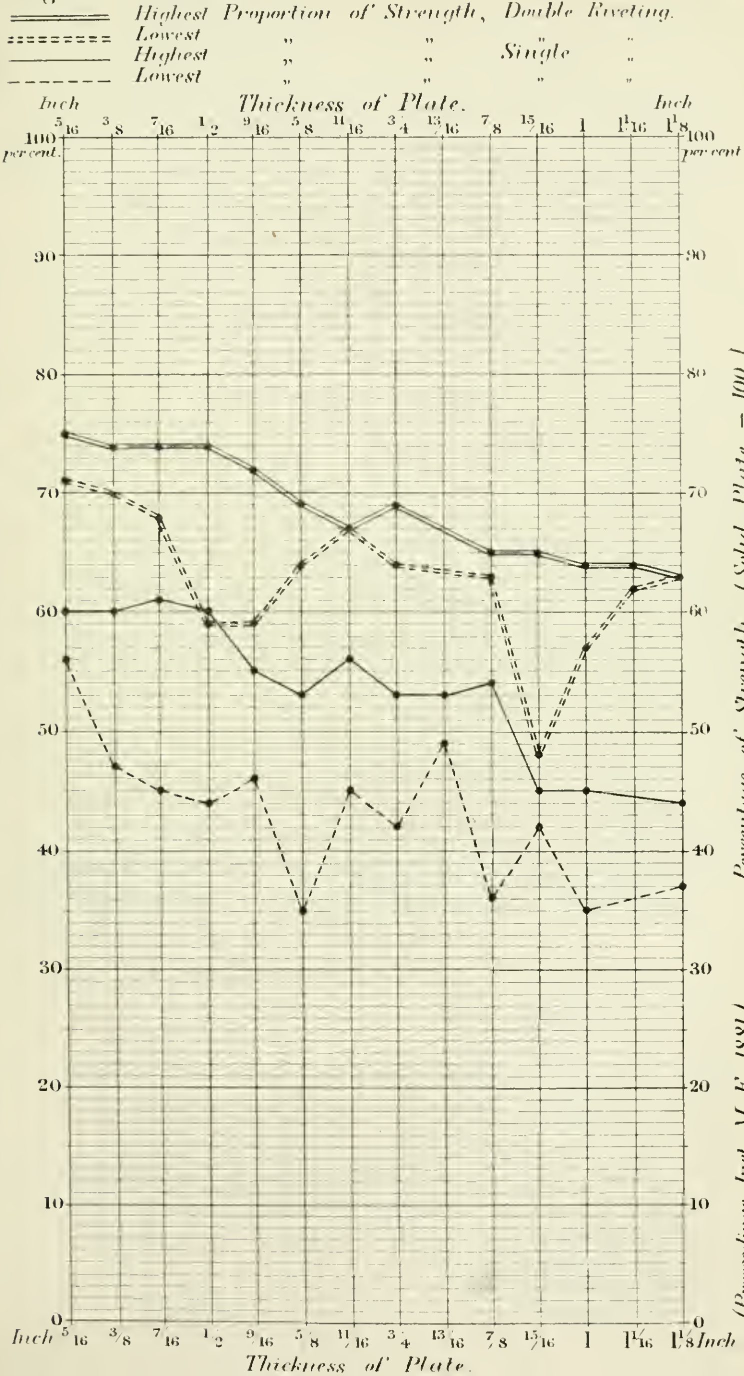


Fig. 19. *Effect of Bending Plates after perforating.*

(Proceedings Inst. M. E. 1881.)

Fig. 20. *Proportion of Strength from Rules of Practice*



FORM OF RIVETED JOINTS. *Plate 34.*

Fig. 1.

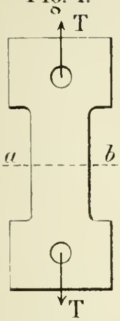


Fig. 2.

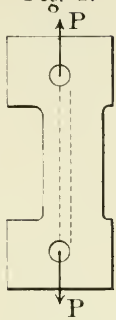


Fig. 2*a*.

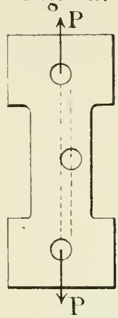


Fig. 3.

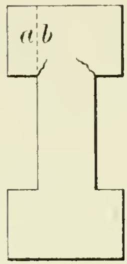


Fig. 4.

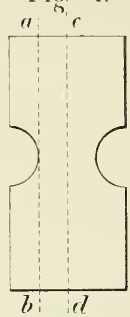


Fig. 5.

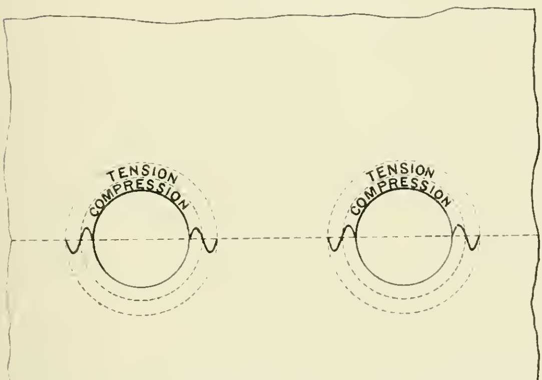


Fig. 6.

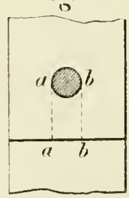


Fig. 6*a*.

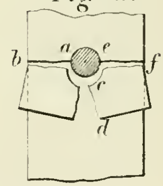


Fig. 7 A.

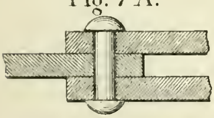


Fig. 7 B.

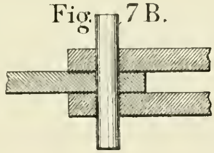


Fig. 7 C.

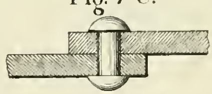


Fig. 8.

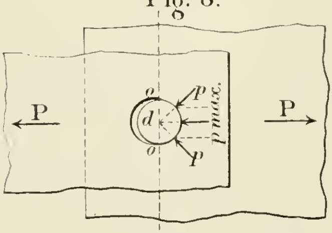


Fig. 10.

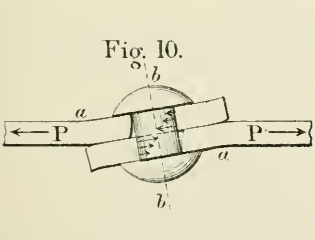
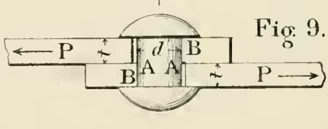


Fig. 9.



(Proceedings Inst. M. E. 1881.)

Fig. 12.

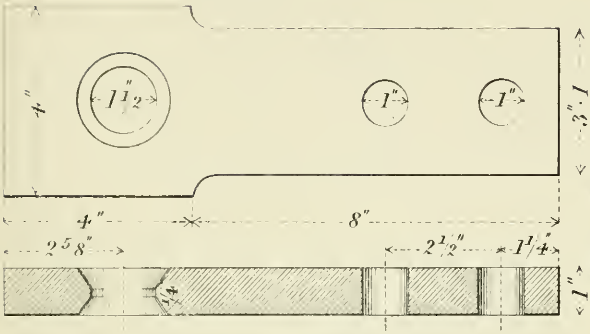


Fig. 13.

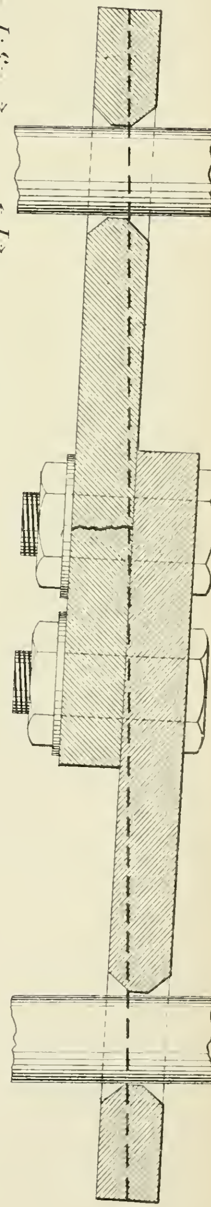


Fig. 11.

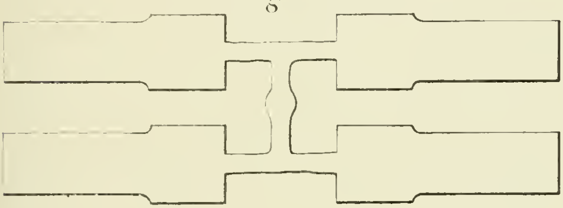


Fig. 14.

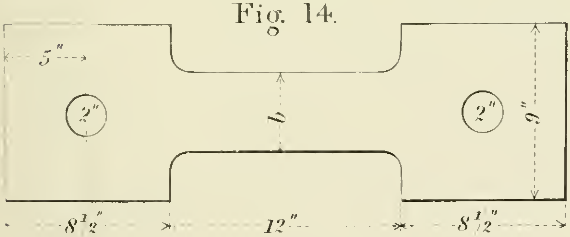


Fig. 15.

Fig. 16.

a *b*

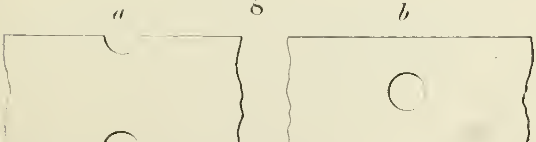


Fig. 17.

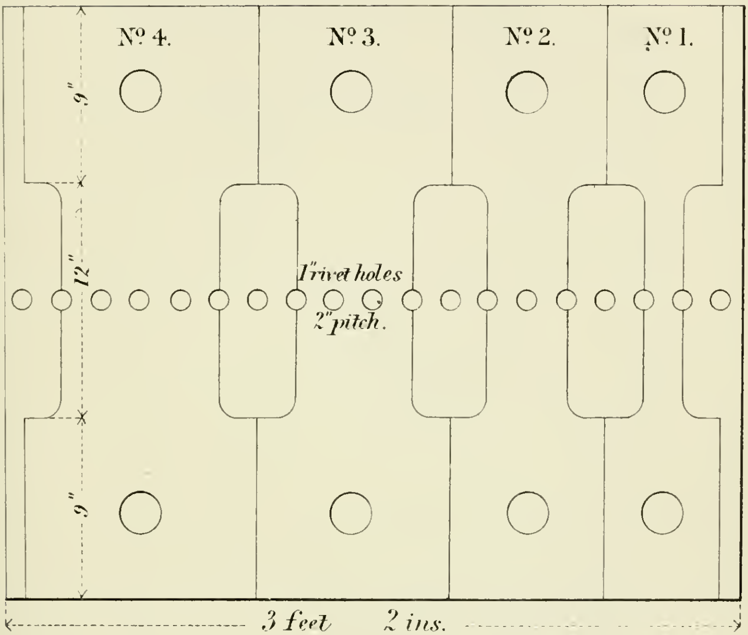
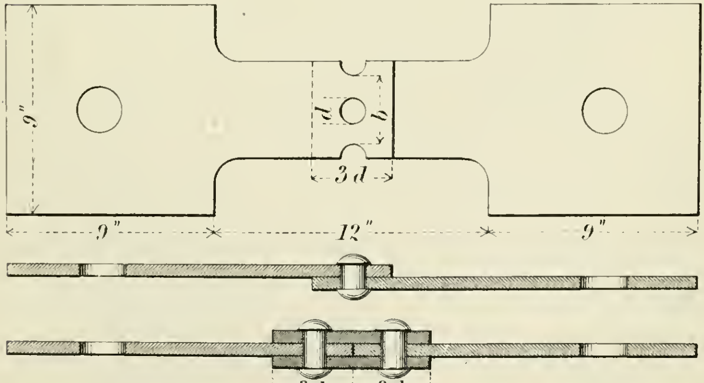


Fig. 18.

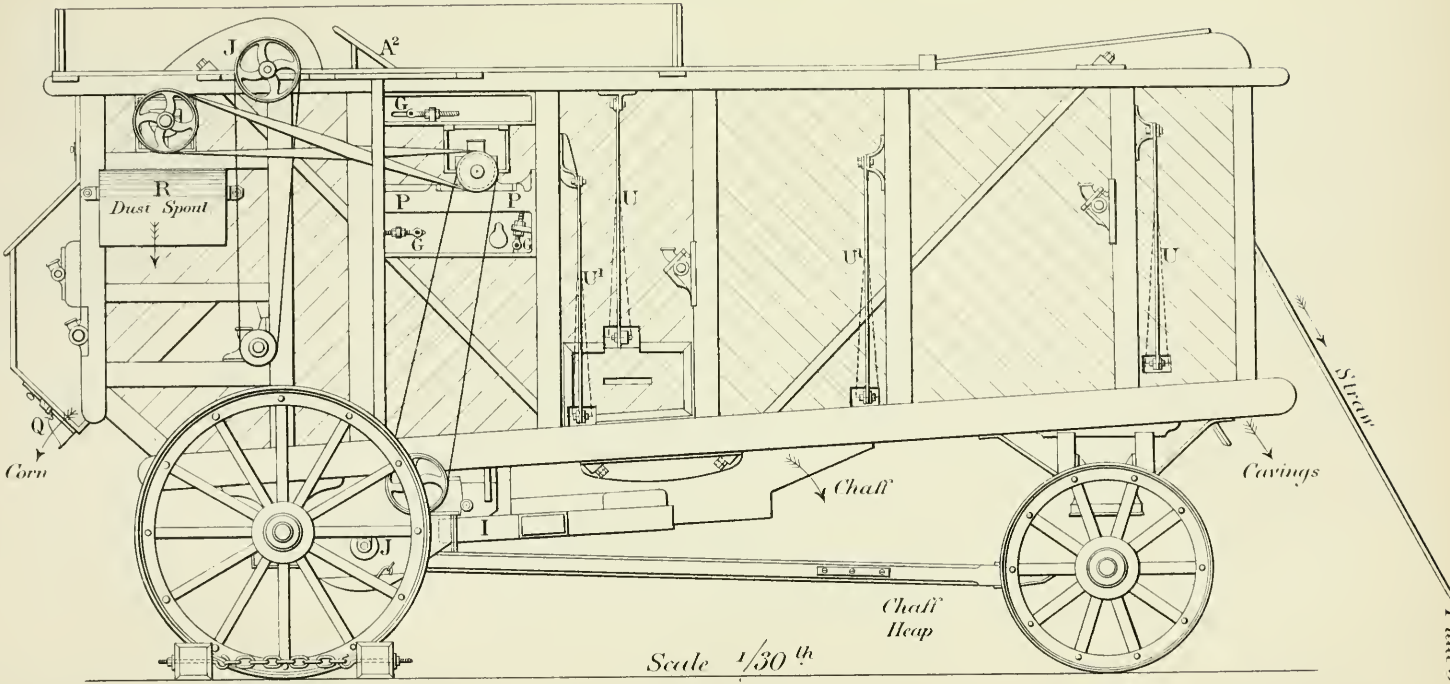


Covers same thickness as plates.

(Proceedings Inst. M. E. 1881.)

THRASHING MACHINES.

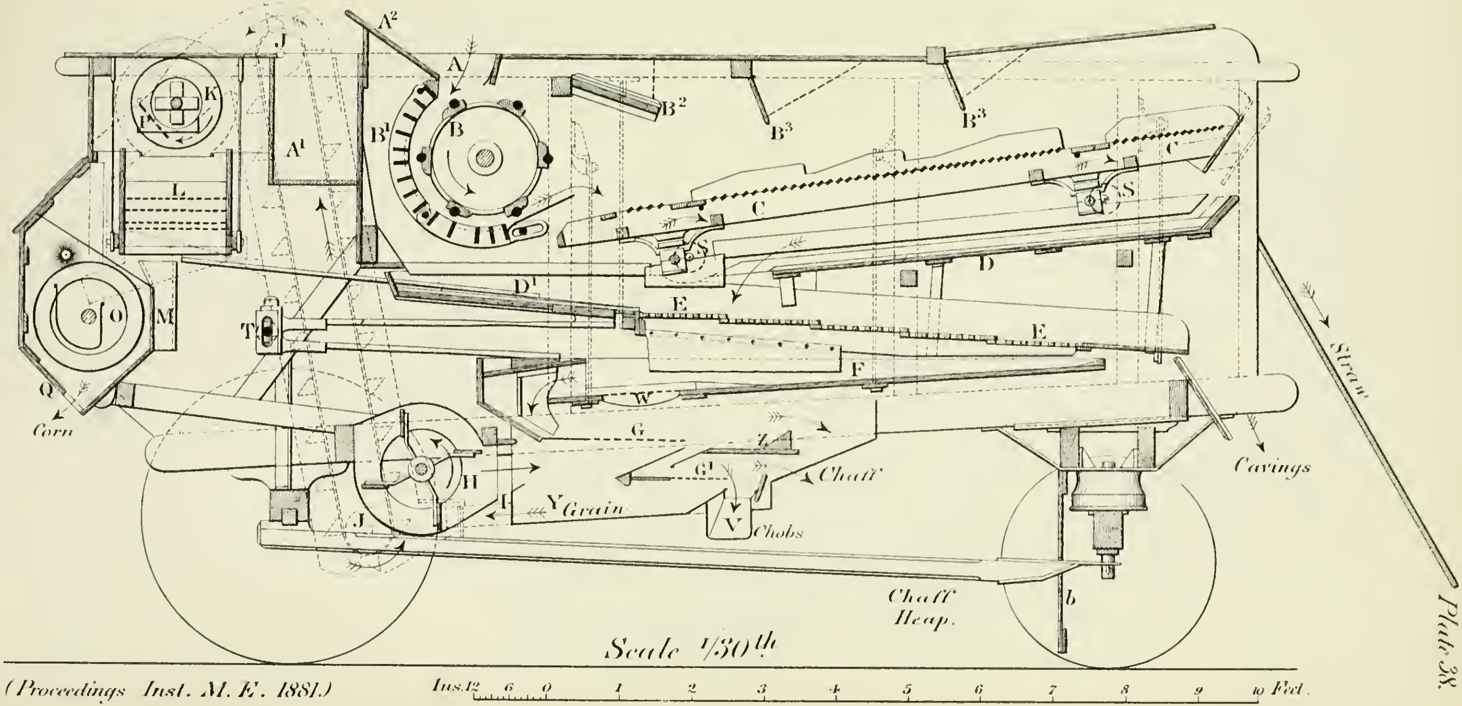
Fig. 1. *Side Elevation of Ransomes' Machine.*



Scale 1/30th

Plate 37.

Fig. 2. *Longitudinal Section of Ransomes' Machine.*



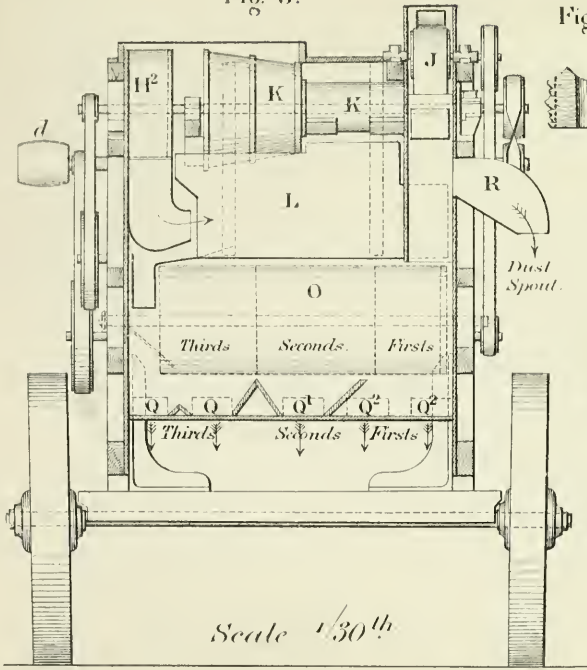
(Proceedings Inst. M. E. 1881.)

Plate 38.

THRASHING MACHINES.

Transverse Sections of Ransomes' Machine.

Fig. 3.

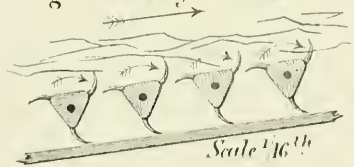


Scale 1/30th.

Fig. 5. *Grooved Caving Riddle Transverse Section.*

Scale 3/8ths.

Fig. 6. *Rotary Shaker.*

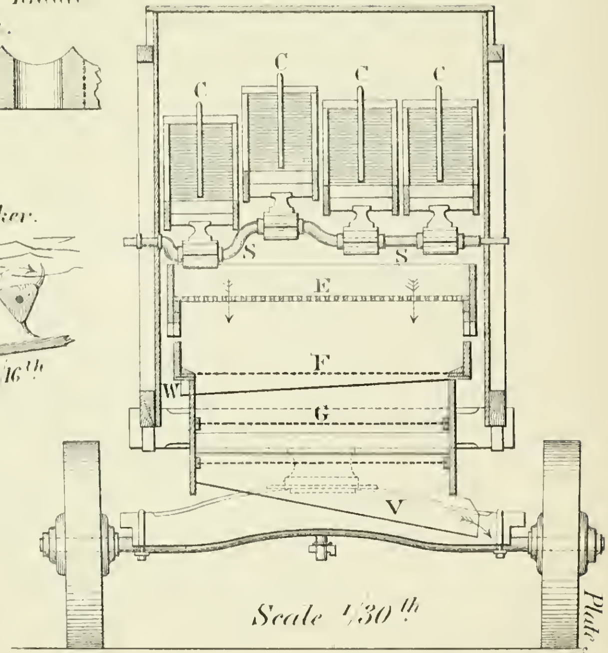


Scale 1/16th.

Fig. 7. *Twisted Beater Bar.*

Scale 3/8ths.

Fig. 4.



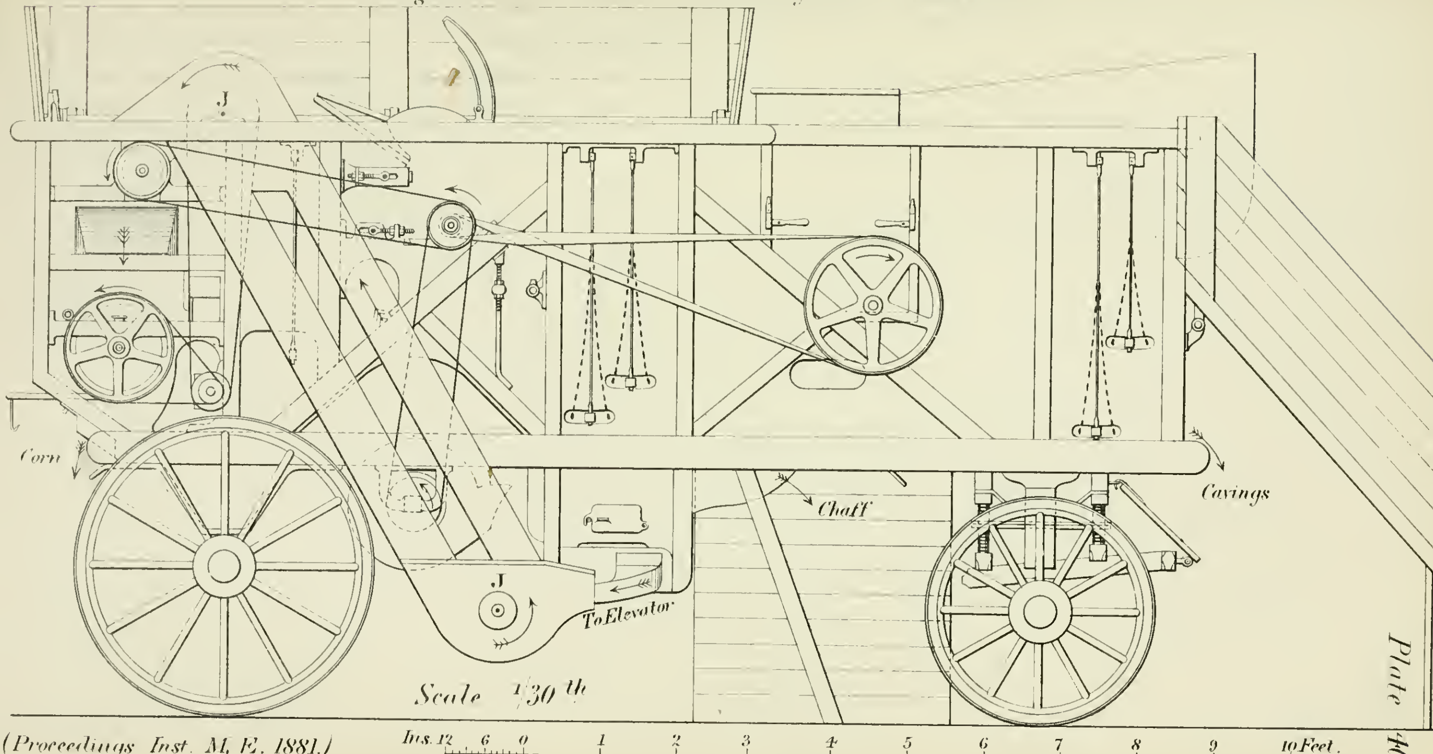
Scale 1/30th.

Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet

Plate 39.

THRASHING MACHINES.

Fig. 8. *Side Elevation of Clayton's Machine.*



THRASHING MACHINES.

Clayton's Machine.

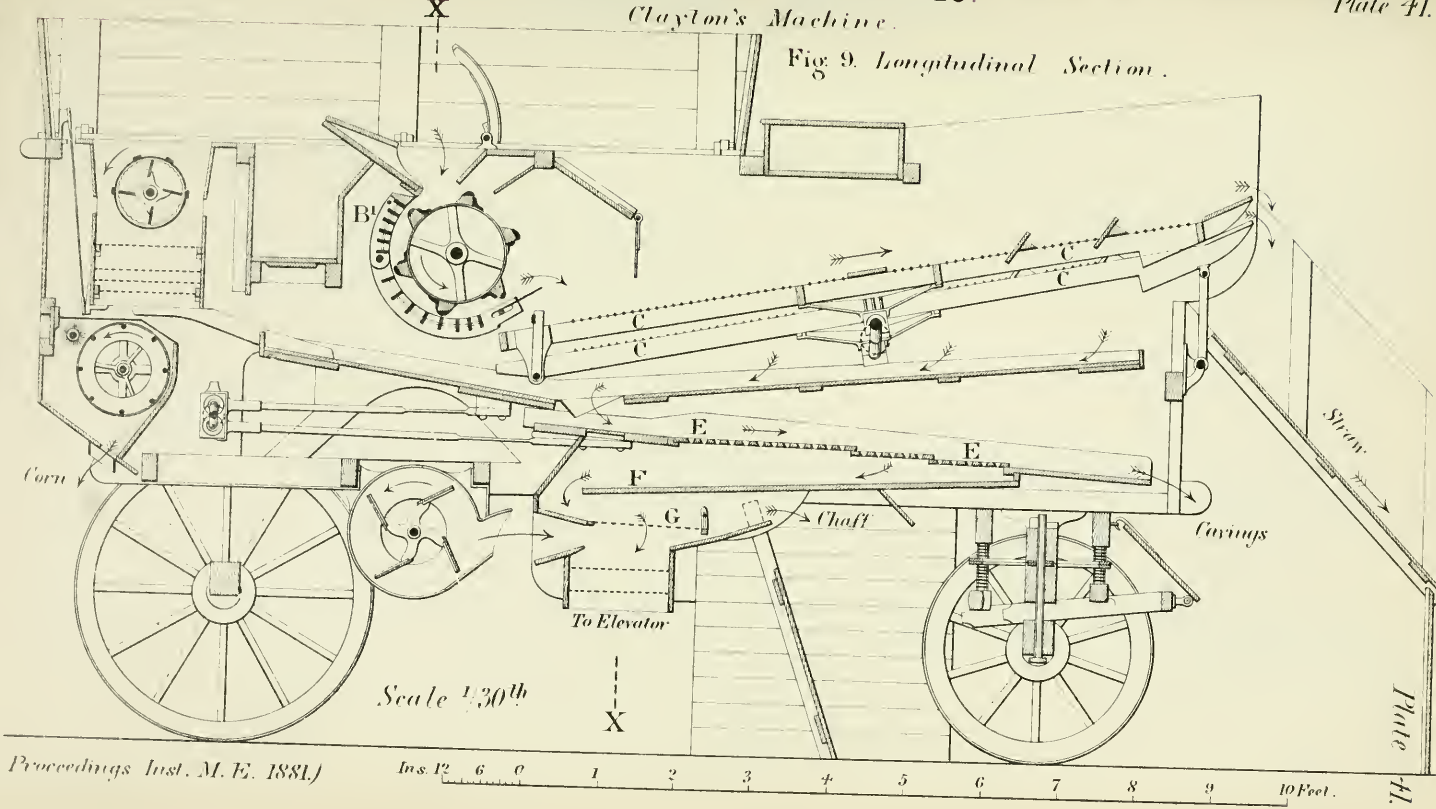


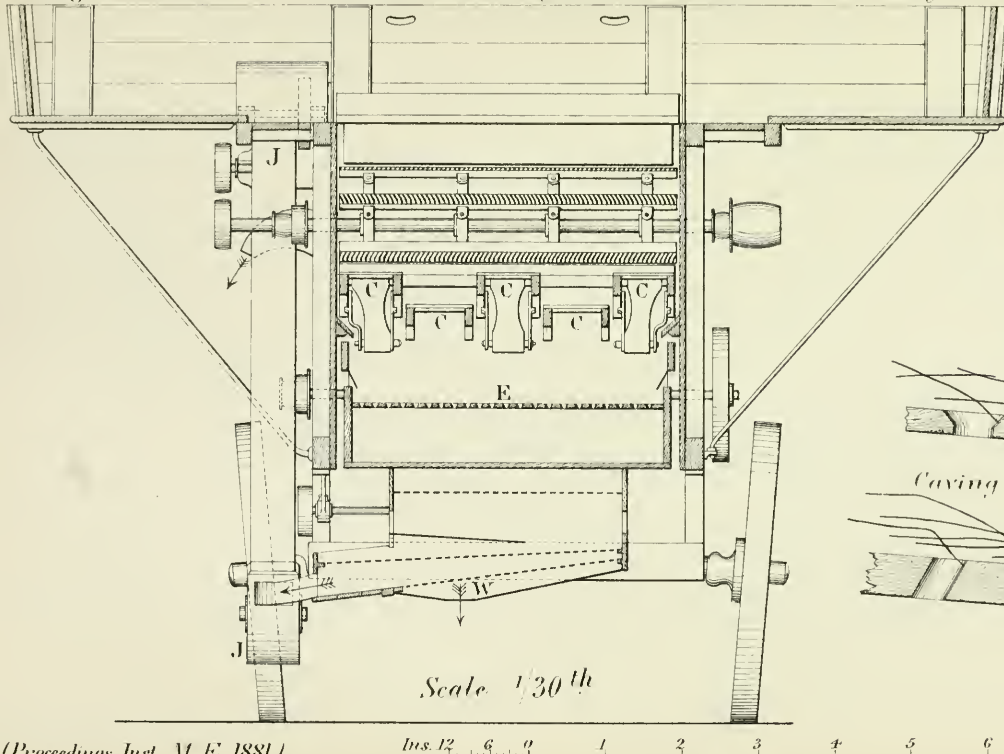
Fig. 9. Longitudinal Section.

Plate 41.

THRASHING MACHINES.

Plate 42.

Fig. 10. *Transverse Section of Clayton's Machine at XX, Fig. 9.*



Scale 1/30th

Fig. 11.

Beater Bar. Scale 1/4th

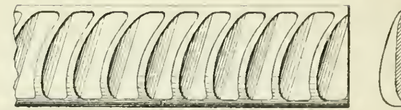
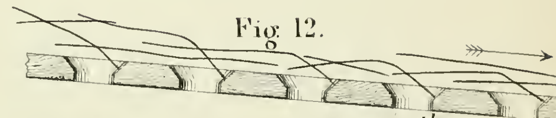
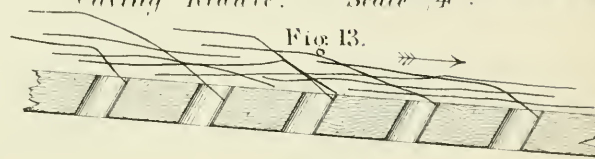


Fig. 12.



Caving Riddle. Scale 1/4th

Fig. 13.



(Proceedings Inst. M. E. 1881.)

Plate 42.

THRASHING MACHINES.

Fig. 14. *Longitudinal Section of Garrett's Machine.*

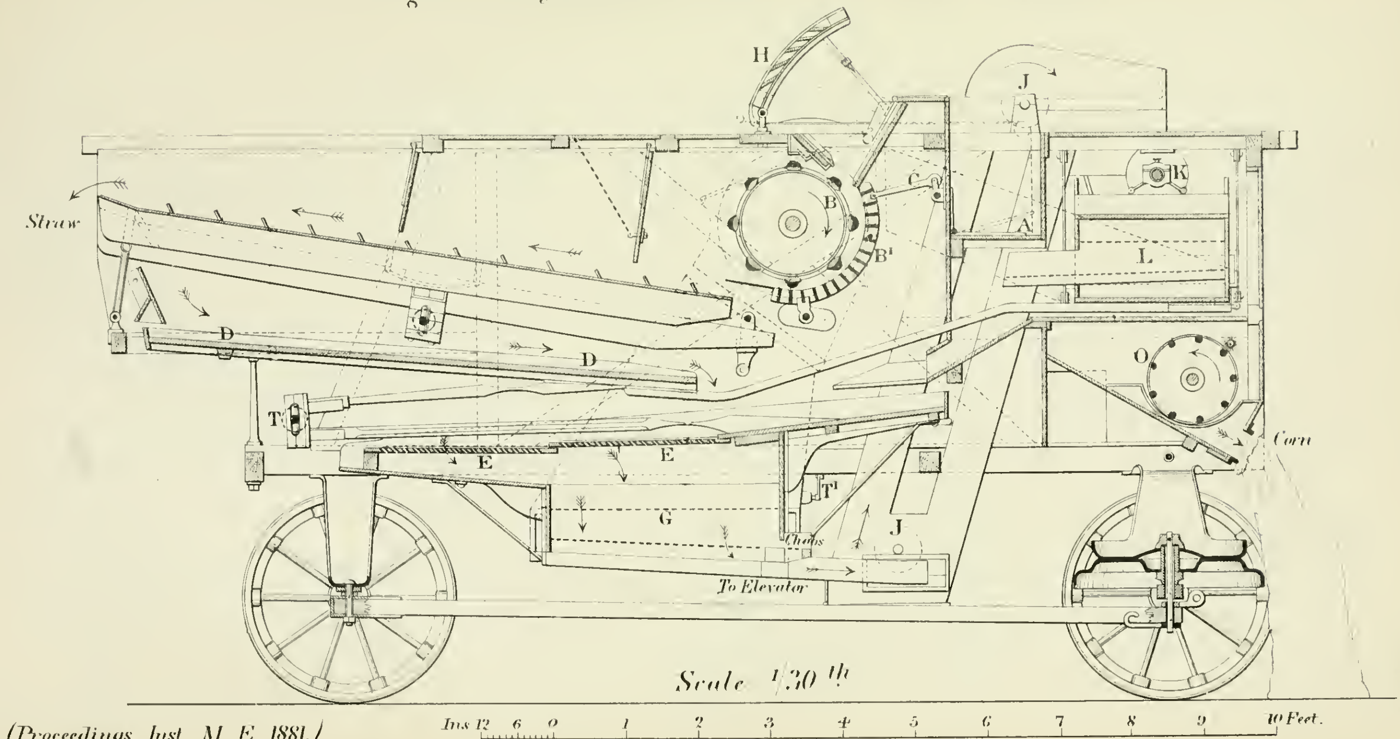


Plate 43.

THRASHING MACHINES.

Garrett's Machine.

Fig. 15. Transverse Section.

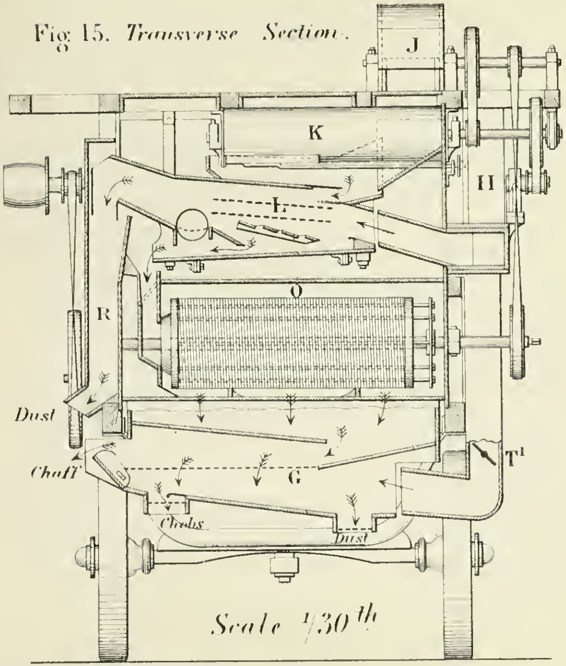


Fig. 16. Side Elevation.

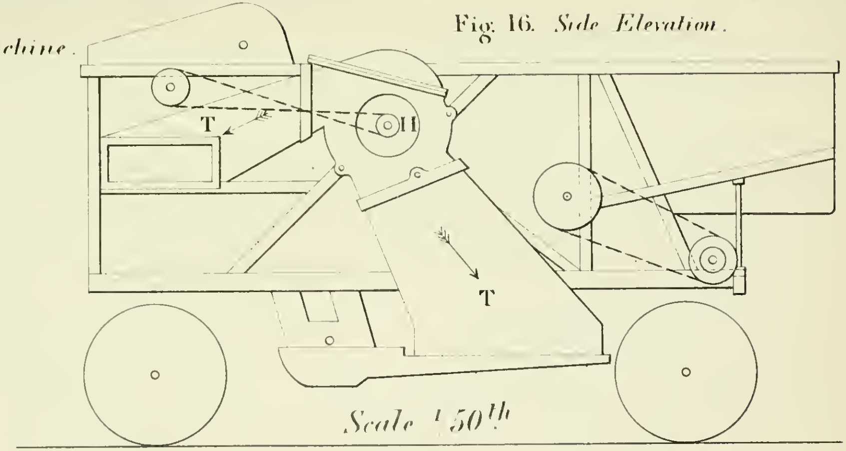
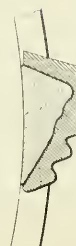


Fig. 17.



Beater Bars.

Scale 1/3rd

Fig. 18.

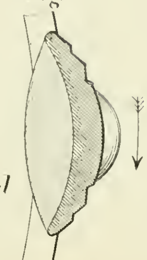
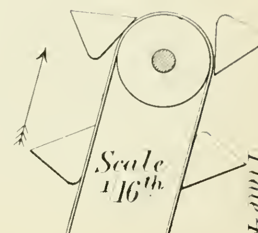


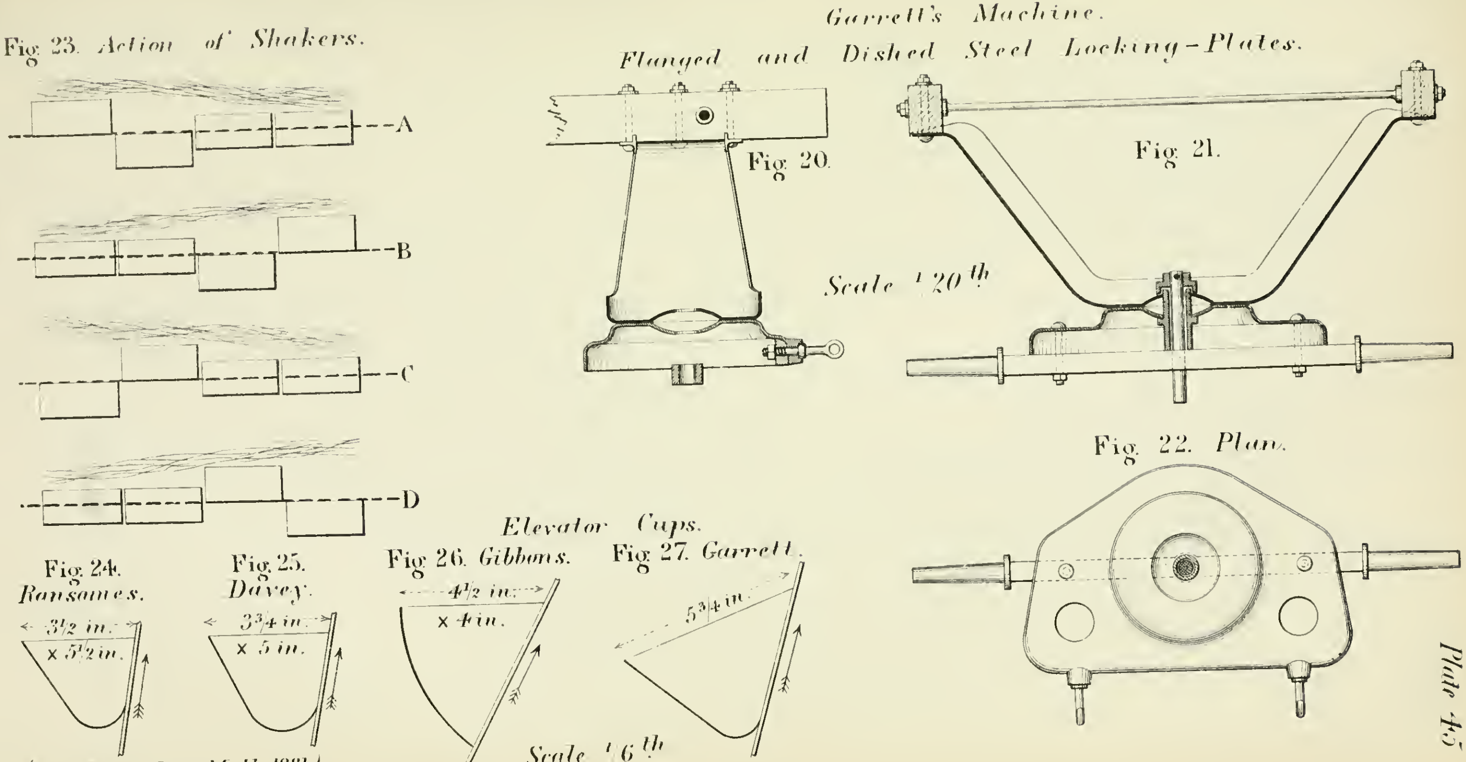
Fig. 19. Elevator.



(Proceedings Inst. M. E. 1881.)

Plate 44

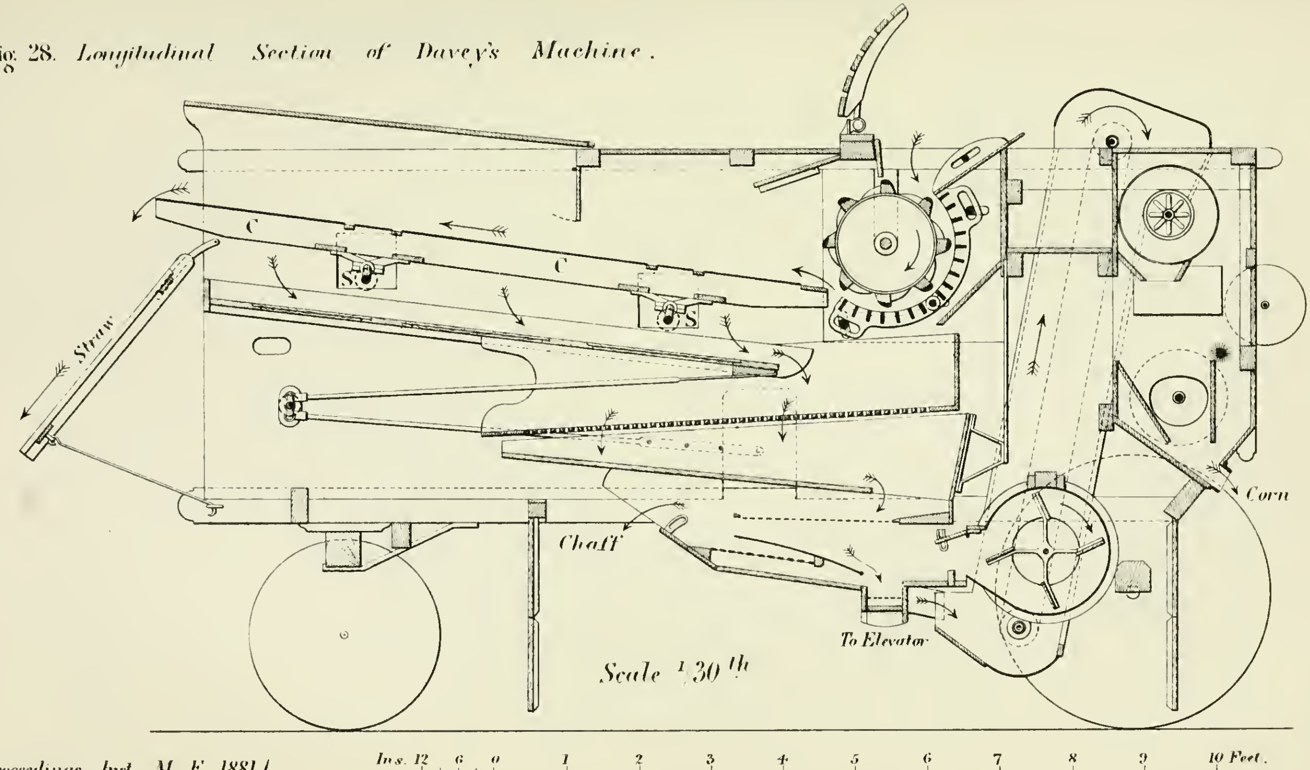
THRASHING MACHINES.



(Proceedings Inst. M. E. 1881.)

Plate 45

Fig. 28. *Longitudinal Section of Davey's Machine.*



(Proceedings Inst. M. E. 1881.)

Plate 46.

Davey's Machine.

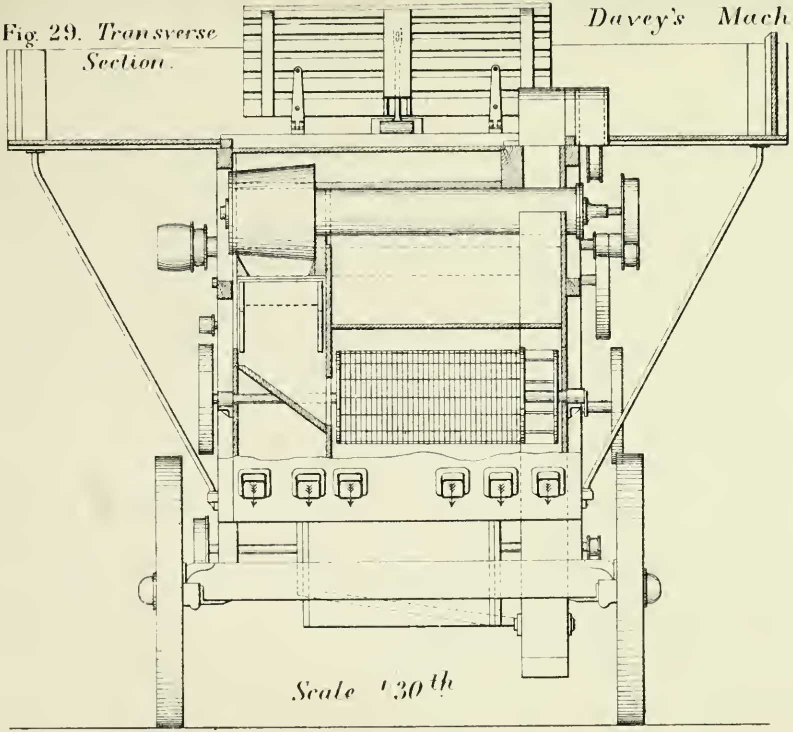


Fig. 29. Transverse Section.

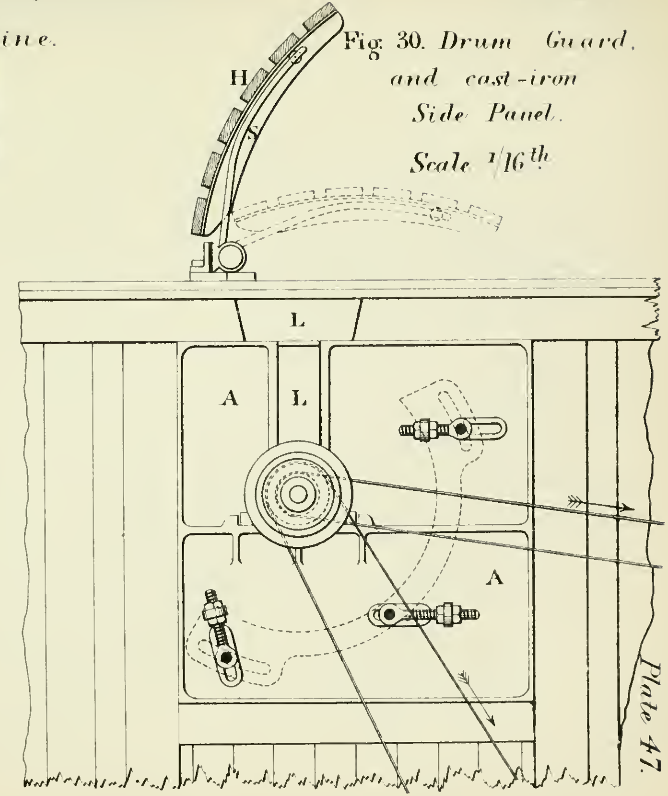


Fig. 30. Drum Guard, and cast-iron Side Panel.

Plate 47.

(Proceedings Inst. M. E. 1881.)

THRASHING MACHINES.

Gibbons' Machine.

Fig. 31. Side Elevation.

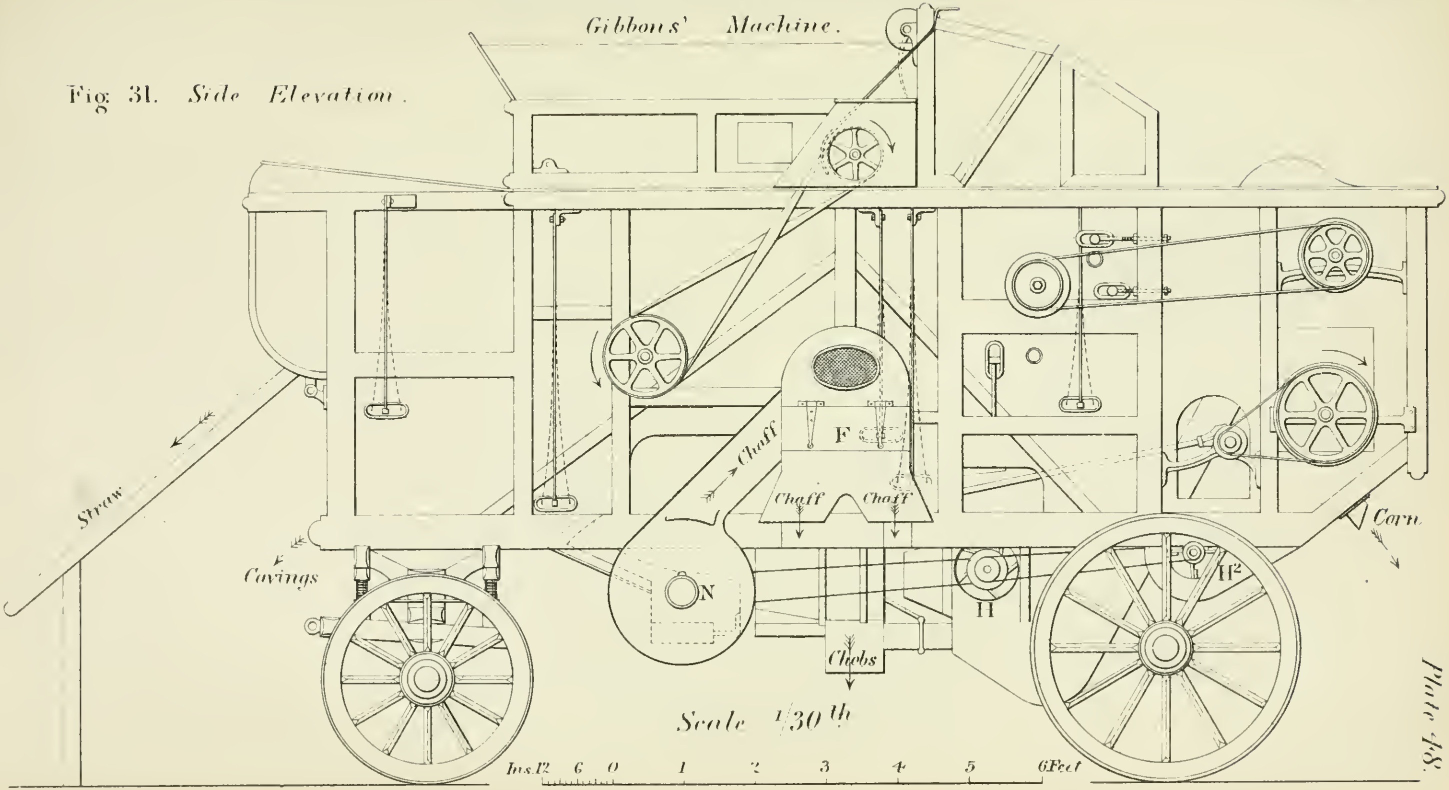
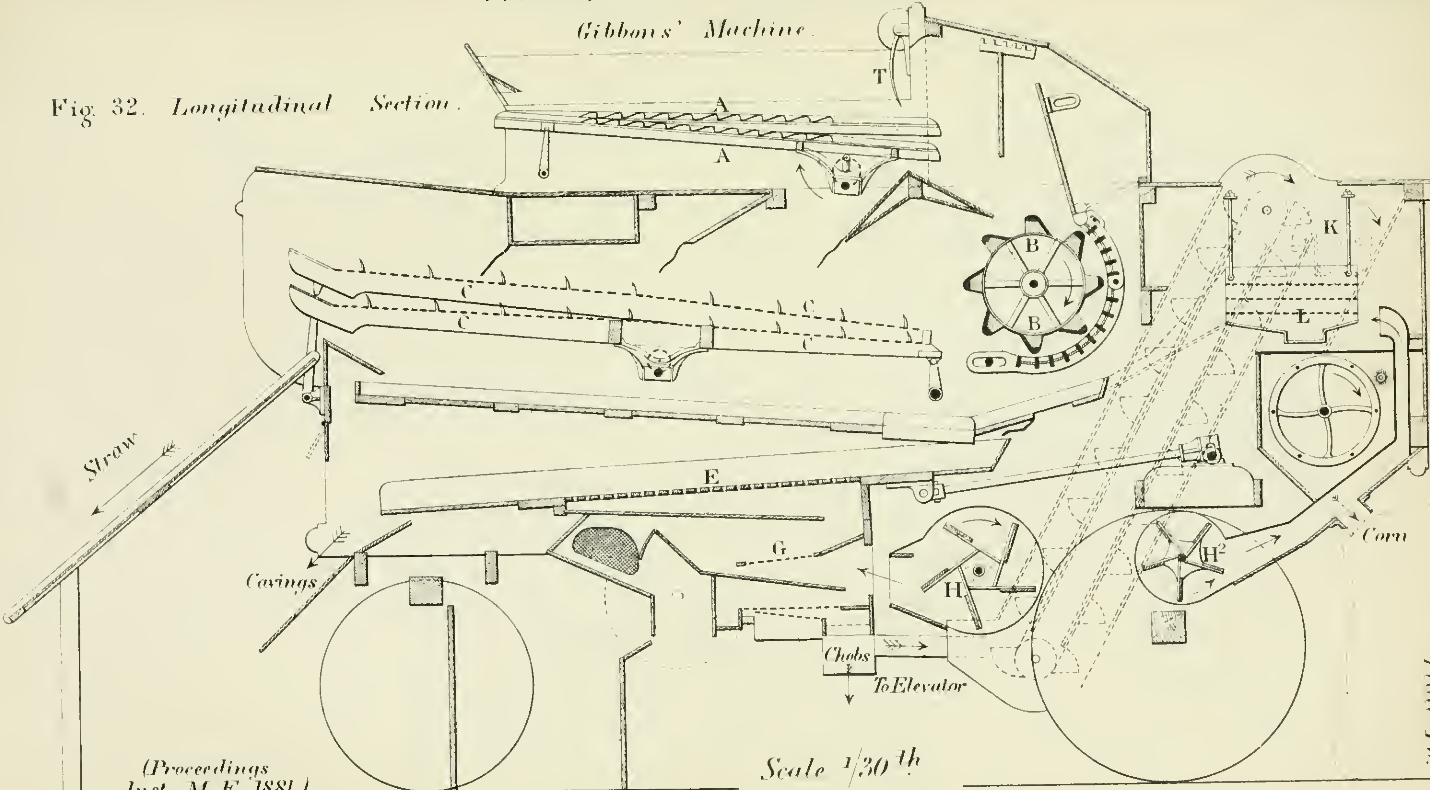


Plate 48.

THRASHING MACHINES.

Gibbons' Machine.

Fig. 32. *Longitudinal Section.*



(Proceedings Inst. M. E. 1881.)

Plate 49.

THRASHING MACHINES.

Gibbons' Machine.

Fig. 34. *Drum Guard Open.*

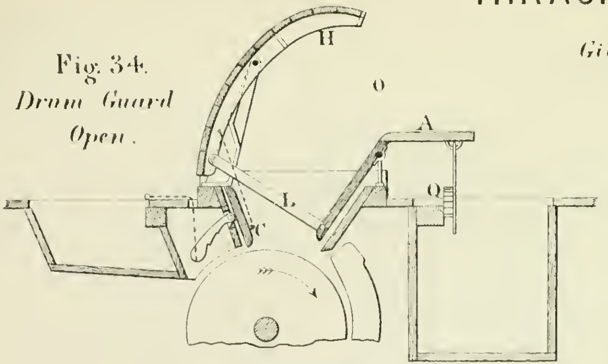
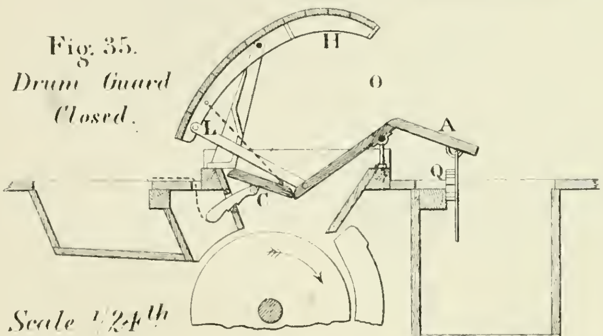


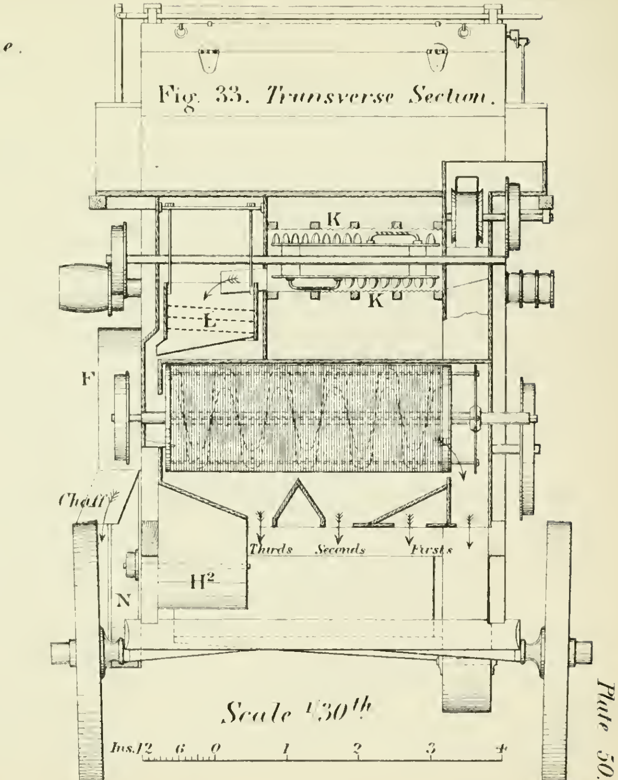
Fig. 35. *Drum Guard Closed.*



Scale 1/24th

Ins.12 6 0 1 2 3 4 5 Feet.

Fig. 33. *Transverse Section.*



Scale 1/30th

Ins.12 6 0 1 2 3 4

(Proceedings Inst. M. E. 1881.)

Plate 50.

Fig. 36. *Longitudinal Section of Robey's Machine.*

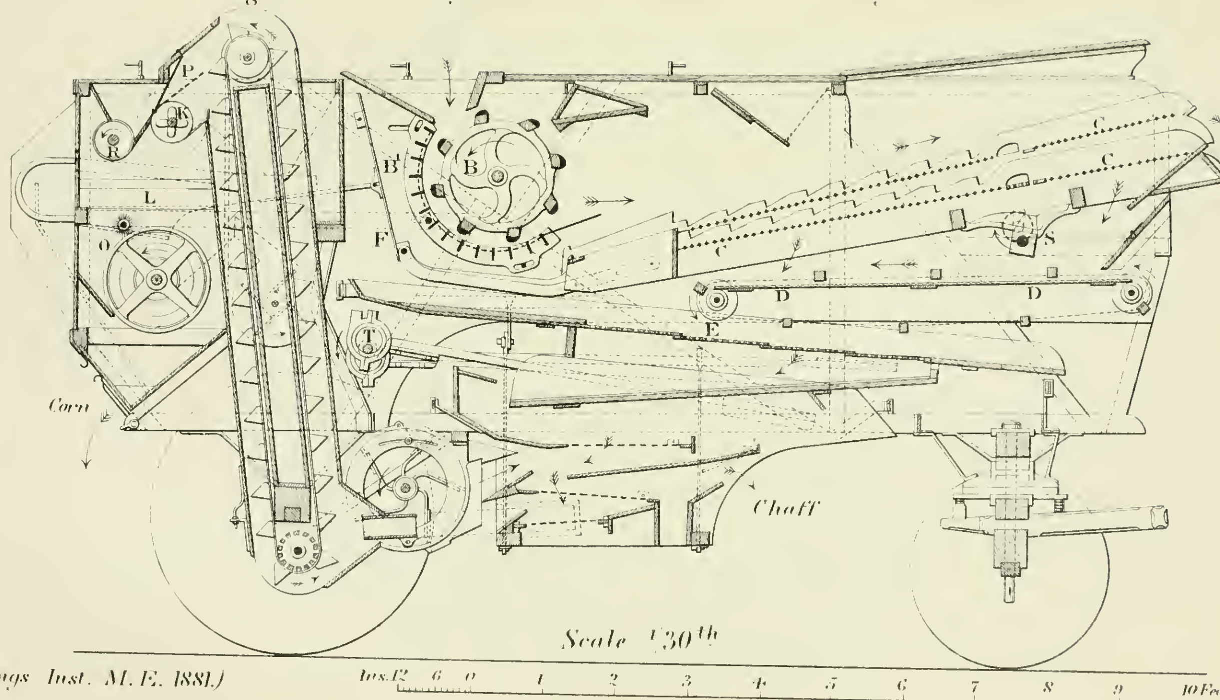
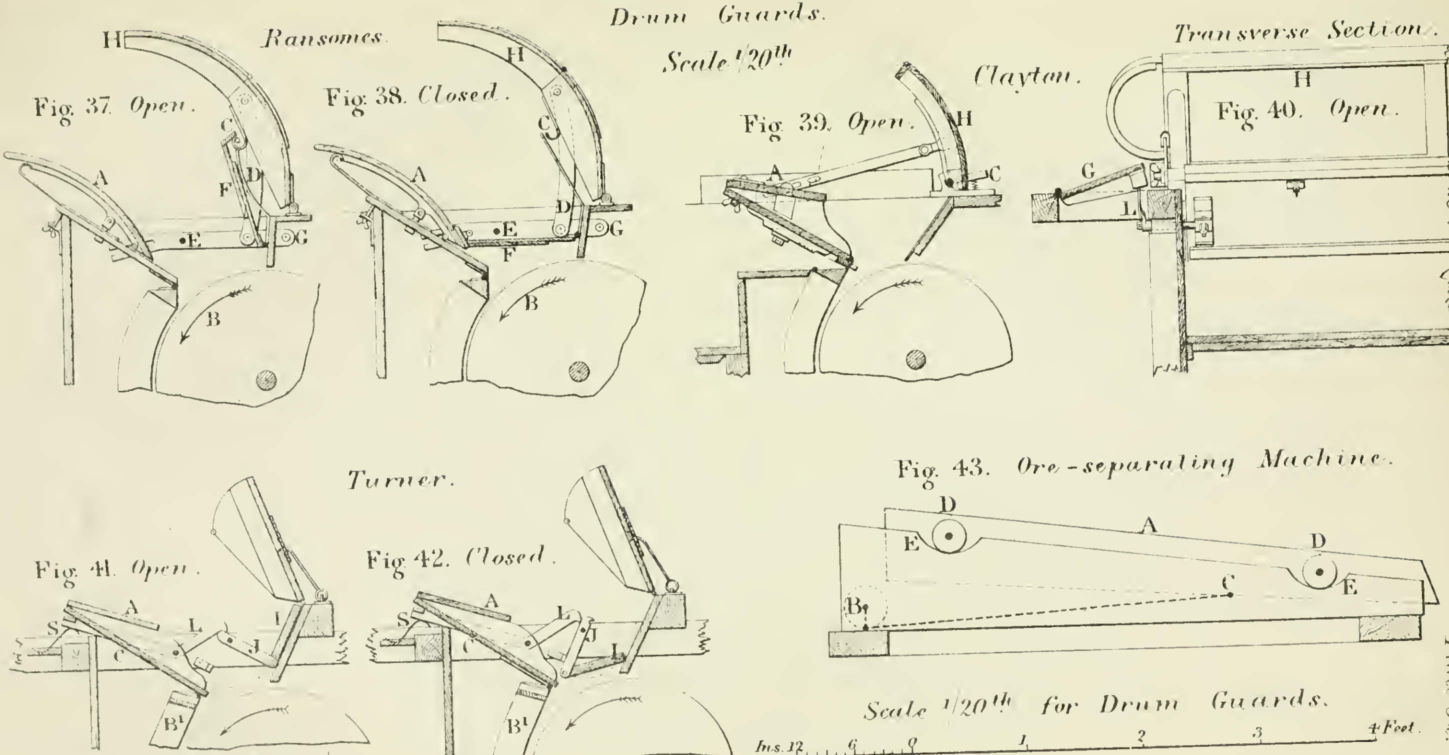


Plate 51.

THRASHING MACHINES.



(Proceedings Inst. M. E. 1881.)

Plate 52.

Institution of Mechanical Engineers.

PROCEEDINGS.

August 1881.

The Summer Meeting of the Institution was held at Newcastle-on-Tyne, commencing on Tuesday, 2nd August, at 10 a.m.; Edward A. Cowper, Esq., President, in the chair.

The Members were received by the Mayor of Newcastle, Jonathan Angus, Esq., in the Lecture Room of the Literary and Philosophical Society.

The Mayor said:—Mr. President and Gentlemen—It affords me very great satisfaction to meet you here on the present occasion, and to give you in my own name, and in the name of the people of Newcastle, a very hearty welcome amongst us. There is no town in the kingdom that should hail your visit with more pleasure than the town of Newcastle. It has for many years taken a prominent part in the science of engineering. It has produced men of whose names I think we may justly be proud—men who have advanced mechanical engineering in its various branches. I need scarcely mention the names of Stephenson, of Hawthorn, and of Sir William Armstrong. These have all done their part in helping forward the world's progress. Theirs are household names among us; and they have established industries, on the progress and prosperity of which this town and district are largely dependent. Therefore, not only in the name of science, but as hoping to advance the progress and prosperity of this district, it is fitting that we should give you a very cordial welcome in our midst. The meetings about to be held here this week are looked forward to with very great interest by thousands of our artisans; and it is my hope that many of them will gather from these meetings knowledge which will help them forward in the

battle of life, and perhaps enable them to take a foremost position in their profession. Such things have occurred before; and I believe that the working classes possess the stamina which will enable them to take advantage of such meetings as the present. Whilst we anticipate from your meetings here great benefit and profit to ourselves, we trust also that they will be the means of pleasure and profit to you. There are many objects of interest in the district; and so far as time will permit, opportunities will be given, which will, I trust, make your visit not only pleasurable but in a high degree successful. I cannot do more than repeat what I have said before, that we give you a very hearty welcome, and trust you will have all the pleasure that you anticipate from your visit amongst us.

The PRESIDENT replied:—Mr. Mayor, I beg to thank you very heartily for the hospitable manner in which you have received us; and to assure you that we had great pleasure in accepting the kind invitation we received to visit Newcastle, to come amongst your celebrated men, and to examine your various works and manufactories. I trust that the benefit of these meetings will be felt, and that the papers and discussions thereon will be read, not only by our own members, but, as you say, by mechanics at large, who always take great interest in our proceedings.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The PRESIDENT announced that the Ballot Lists for the election of New Members had been opened by a Committee of the Council, and the following candidates had been found to be duly elected:—

MEMBERS.

WILLIAM JOHN ADAMS, . . .	London.
PERCY RUSKIN ALLEN, . . .	London.
GEORGE WILLIAM BROWN, . . .	Reading.

Brodie Cochrane, ...	Durham.
Arthur Coote, ...	Newcastle-on-Tyne.
Thomas Cosser, ...	Kurrachee, India.
Patrick Walter D'Alton, . .	London.
Benjamin Davies, ...	Chorley.
Joseph Emerson Dowson, . . .	London.
Frederick William Jackson, .	London.
Herbert Edward Jones, . . .	Manchester.
Ramsey Kendal, ...	Gateshead.
William Langdon, ...	Huelva, Spain.
Alexander Lavalley, . . .	Paris.
John List, ...	London.
Léon Molinos, ...	Paris.
Frederick Newman, ...	London.
John Philipson, ...	Newcastle-on-Tyne.
Henry Conrad Sanders, . . .	London.
James Scott, ...	Port Elizabeth.
William Shapton, ...	London.
William Shaw, Jun., . . .	Wolsingham.
Robert Henry Smith, . . .	London.
Wasteneys Smith, ...	Newcastle-on-Tyne.
Henry Hay Wake, ...	Sunderland.
Richard Landor Warham, . .	Derby.
Edward Malcolm Wood, . . .	London.

ASSOCIATE.

John Grayson Lowood, . .	Sheffield.

GRADUATES.

Gordon McDakin Clench, . .	Lincoln.
Moraston Ormerod Norris, . .	Glasgow.
Ernest Scott, ...	Newcastle-on-Tyne.
Frank Walkinshaw, . . .	Winchfield.

The PRESIDENT then delivered his annual Address.

A vote of thanks to the President for his Address was moved by Mr. Abernethy, President of the Institution of Civil Engineers, and seconded by Sir Frederick Bramwell, F.R.S., and was passed by acclamation.

The following paper was then read:—

On the Tyne, as connected with the History of Engineering; by Mr. I. Lowthian Bell, F.R.S.

The President proposed a vote of thanks to Mr. Bell for his very interesting paper, which was carried unanimously.

The following paper was then read and discussed:—

On the Progress and Development of the Marine Engine; by Mr. F. C. Marshall, of Newcastle.

At 1 P.M. the discussion was adjourned till the following day.

The Adjourned Meeting of the Institution was held in the Lecture Room of the Literary and Philosophical Society, Newcastle-on-Tyne, on Wednesday, 3rd August 1881, at Ten o'clock, A.M.; EDWARD A. COWPER, Esq., President, in the chair.

The discussion upon Mr. F. C. Marshall's paper on The Marine Engine was resumed, and concluded.

The PRESIDENT proposed a vote of thanks to Mr. Marshall for his very excellent and practical paper; which was carried by acclamation.

The following paper was then read and discussed:—

On Printing Machinery; by Mr. John Jameson, of Newcastle.

On the motion of the President, a vote of thanks was unanimously passed to Mr. Jameson.

The PRESIDENT said he had now a pleasant duty to perform. The Council had that morning been considering the question as to who should next fill the chair, which he, by the kindness of the members, had occupied for nearly two years. It was always an anxious matter with them to select a gentleman, who would fill the office of President with the greatest benefit to the Institution. Their old friend Mr. Menelaus had been requested to take the position; but for various reasons he had declined the honour. The matter had been further considered by the Council, and they intended to nominate in October, when the nomination had to be made, Mr. Percy G. B. Westmacott of Newcastle—a gentleman than whom no one could fill the office with greater ability. He had been attentive at the Council meetings, and was a very useful and active member of Council. He thought they could not select a gentleman more fitted to fill the chair with benefit to the Institution, and with advantage to the community.

The Meeting was then adjourned to the following day.

The Adjourned Meeting of the Institution was held in the Lecture Room of the Literary and Philosophical Society, Newcastle-on-Tyne, on Thursday, 4th August 1881, at Ten o'clock, A.M.; EDWARD A. COWPER, Esq., President, in the chair.

The following papers were read and discussed:—

On some recent improvements in Lead Processes; by Mr. Norman C. Cookson, of Newcastle.

On a Feed-Water Heater and Filter for Stationary and Locomotive Boilers; by Mr. George S. Strong, of Philadelphia.

On Iron and Steel as Constructive Materials for Ships; by Mr. John Price, of Jarrow.

On Slipways; by Mr. William Boyd, of Wallsend.

Votes of thanks were severally passed to the authors, on the motion of the President.

The PRESIDENT proposed the following Votes of Thanks, which were carried by acclamation :—

To the Literary and Philosophical Society, and the North of England Institute of Mining and Mechanical Engineers, for their kindness in granting the use of their rooms for the purpose of the present meeting, and for the facilities afforded by them.

To the General Committee, the Engineers and Shipbuilders of Sunderland, and those Firms who have so liberally offered hospitality to the members during the meeting.

To those Firms in Newcastle, Sunderland, and the district, who have thrown open their Works to the members during the meeting.

To the Directors of the North Eastern Railway, and of the Tyne General Ferry Company, for their kindness in granting special free trains and steamers for the Excursions.

To the Committee of the Union Club, for the facilities offered to the members of the Institution to become honorary members of the Club for the week.

To the Executive Committee, and their Chairman, Mr. Percy G. B. Westmacott, Vice-President, and to the Honorary Local Secretaries, Mr. William Boyd and Mr. J. Cartmell Ridley, for their valuable services in maturing all the arrangements for ensuring the success of the Meeting.

The Meeting then terminated.

PRESIDENT'S ADDRESS.

Gentlemen,

I feel that we, as members of the Institution of Mechanical Engineers, on revisiting our brother members and friends here in Newcastle, after an interval of twelve years, come as it were to one of our natural homes; certainly to the home of one of the greatest engineers that England has ever produced, and the birthplace of the locomotive, which has done more than any other improvement of our age to lessen the cost of materials to the men who have to use them, and therefore to cheapen and extend production in the most wonderful manner.

It seems but a few years ago that George Stephenson, at a meeting in 1847, proposed the resolution that the Institution of Mechanical Engineers be formed. He was strongly supported by a large number of the mechanical engineers of the country, and I had the honour of seconding the resolution that he be our first President.

The intention was, that engineers, from all parts of the country, should join to form a compact body, capable of discussing and judging of all mechanical subjects and appliances. In this the Institution has been eminently successful, and it numbers among its members mechanical engineers in every large town in the country, and is ever increasing in strength and importance.

I have said that it seems but a short lifetime, from the birth of the Institution, and the presidentship of "old George," to the present time; but the interval of time since our last visit to our good friends here seemed but such a very few years, that one was really tempted to consider if we were not trespassing a little too soon on their kindness; but I think (and I speak to our numerous members visiting Newcastle) they will find, that the very kind and pressing invitation we received last year to come here on this occasion was really one of such a hearty and hospitable character, as to preclude any idea of our hesitating to accept it in the same hearty manner in which it was presented. The number of members who have signified their

intention of coming here is much larger than usual on such occasions, being over 300.

The last twelve years have been marked by many very important changes, whilst low prices have generally ruled. Amongst other causes of fluctuations in demand and supply (and consequently in values), must be mentioned the occurrence and the threatening of foreign wars, which disturbed the course of commerce greatly for some years. Such causes must be considered as extraneous to the sphere of influence possessed by good or bad manufacturing or engineering.

In certain cases, no doubt, the demand for improved war material and implements called forth that talent and energy for which Englishmen ought always to be celebrated; and greatly improved arms were produced, and nowhere in greater perfection than in this very neighbourhood.

Now I am not one of those who look upon the very great expense of improved war material and implements as an unmixed evil for this country; for it so happens that we can better meet such outlay than any other nation, and thus our wealth gives rise to greater power and security than our neighbours possess; while, seeing that we are not an aggressive nation, such power tends materially at once to the progress of this country, and to the peace of the world.

Having referred briefly to one cause of disturbance to the progress of mechanical engineering, allow me to name another, which at the present moment is occupying thoughtful men to a considerable extent. I refer, of course, to the arbitrary imposition of duties and bounties for the professed object of protecting manufactures, whilst in fact they constitute taxes on a nation for the benefit of a few individuals.

In some countries excessive duties have been imposed, as against our manufactures, and it is even proposed to increase them; whilst in other cases, bounties are actually paid out of the public purse to men engaged in a particular manufacture, on their exporting to this country certain of their wares, as for instance beet-root sugar.

One extremely significant lesson, resulting from high duties, (which it may be hoped will not be thrown away upon the American

public) is, that whereas our cousins on the other side of the water used to build almost all the American "liners," of wood, they now find that, with their excessive duties against the importation of iron and steel from England, they cannot compete with English iron and steel shipbuilders and marine engineers. This is one of those damaging effects naturally produced by excessive protective duties; which, whilst they enable American ironmasters quickly to realise enormous fortunes, drive the American merchants to purchase English ships, or entrust their merchandise in English bottoms, as it is impossible to maintain protective duties at sea. I cannot here avoid remarking that American ironmasters are extremely quick in adopting any improvement that will increase their "make," and reduce their fuel account: if proof were wanting, the fact of an American blast furnace producing 1,200 tons of iron a week from a 20 ft. bosh might be cited.

Whatever fluctuations have occurred, it is now pretty clear that several foreign nations have settled down to cultivate and extend their manufactures; and we are brought face to face with the fact (which has now been for some years growing to its present importance) that many articles which in years gone by we thought it to be our especial province to supply, are now produced in the very countries requiring them. I need hardly name locomotives, steel rails, stationary engines, rolled girders, bar iron, pig iron, and castings generally.

Even Spain is awakening to the advantage of producing hæmatite iron from her own excellent ores, with English and Welsh coke carried out in the same ships that bring Spanish ores to this country.

Now with regard to the possibility of any foreign nation eclipsing us in our manufactures—I mean in some of those manufactures which seem most naturally to belong to us, and for which we have special facilities—I would say at once that any such successful rivalry on their part is far worse than the effect of any duties, even if they be prohibitive; for it means rivalry in the markets of the world, and possibly in our own markets here at home.

Of course, if low prices are likely to rule, as they have done now for some years in most departments of mechanical engineering

(though I am one of those who look forward to some improvement), it behoves us to put our house in order, and see in what way we may be enabled to manufacture better and with greater economy; and it is a fact we all admit (if our practice does not always accord with it), that if we manufacture better, we are sure to manufacture cheaper.

When I speak of "manufacturing," in contradistinction to "making by hand," or entirely by rule of thumb, I mean the producing a material, or article, or finished machine, of better quality, more uniform, of better finish, made more accurately to gauge, more economical in action, and, by the aid of invention, simpler and more effective generally.

Now mechanical engineering is of such extreme importance, in advancing civilisation, that it is most essential that its progress should be rapid and unimpeded. I wish, therefore, to note the great influence upon the material interests of the world, exercised by the improvements that have been made in the past twelve years even, as an incentive to all of us to reach forward to further improvements and discoveries in the future.

Perhaps the very large increase in steam shipping, with the change from sailing ships and paddle steamers to screw steamers, has proved one of the greatest improvements of recent times; and it is none the less real or important from having been gradual, while the result to this neighbourhood has been most beneficial. This change has been due in great measure to the introduction of very economical marine engines, chiefly of the compound type, together with better boilers carrying a higher pressure. The speed and regularity of ocean steamers has also greatly improved, and one small scientific improvement has added much to the safety of traversing such seas as the Atlantic at a high speed—I mean the careful and continual use of a good thermometer, to ascertain constantly the temperature of the sea water at the surface. For, if an iceberg is floating within a quarter of a mile (or even half a mile if the sea is pretty smooth), the surface water will be several degrees colder than the rest of the sea; since the very cold fresh water, resulting from the melting iceberg, floats on the top of the sea water for some distance.

No doub. the use of iron, and now of steel, has contributed most

largely to the increase of shipbuilding in this country. Good arrangements of water ballast have also proved very useful; and steam cranes, and arrangements for loading and discharging cargo, have greatly promoted the use of steam colliers, enabling them to make more voyages in the year.

Whilst speaking of the speed of ships, I must not omit to notice the very high speeds first obtained by Mr. Thornycroft, on the Thames, from torpedo-boats and other small craft. To those who enjoy, for the first time, a run at twenty or twenty-two miles an hour in a small boat, the sensation is really a novel one. The voyage of Mr. Perkins' little boat, the *Anthracite*, safely across the Atlantic and back again, is also one of those remarkable performances that are well worthy of note. I trust we shall have a good discussion on Mr. Marshall's and Mr. Price's papers upon these subjects.

Closely connected with marine engineering, is the great improvement in the economy of stationary engines, which has become more fully developed during recent years, in reference both to water-works engines and to factory engines.

In aid of stationary engines, "surface evaporator condensers" have been found very useful, particularly where the supply of water is very limited; and at water-works it is now very common to pass the whole water pumped through a surface condenser, thus giving a good vacuum without the expenditure of any water, and with the result of only raising the temperature of the water a very few degrees, on account of its large volume.

Locomotives have shared to some extent in the general improvement in machinery. The boilers are better made, and are safer at the higher pressures now carried than they were formerly with a lower pressure. Several new valve gears of great promise have been brought forward, both for locomotives and marine engines.

Amongst these Joy's motion should be again noticed, and I have in my hand a note from Mr. Webb (who I am sorry to say cannot be with us to-day), in which he refers to his promise of last year to report on the subject to the members. He says, "The engine "has been continuously at work ever since the Barrow meeting, and had

" run 30,273 miles up to the 18th July, when we had it in for " examination, and found the motion practically as good as the day it " went out of the shop, more especially the slides, about which so many " of the people who spoke at the meeting seemed to have doubts. I do " not think you could get a visiting card between the slides and the " blocks; in fact, the engine has been sent out to work again, having " had nothing whatever done to it. The first thing of course that " will require doing will be the tyres: as far as I can see nothing " else will want doing for some time."

Automatic continuous brakes are now coming into use, adding greatly to the safety of railway travelling; indeed, it has for some time been obvious, that with the higher speed and greater number of express trains, some more powerful means of stopping quickly than the old guard's brake van has become absolutely necessary; and the advantage of being able to stop a quick train in 250 yards is self-evident.

Improvements have been made in the direction of ensuring greater safety on Railways during the last dozen years, as the " Block System " has become general, and interlocking of signals and switches, and the use of switch locks, &c., have become the rule instead of being the exception.

A very fine engineering work has now been accomplished in America in reference to Navigation: I allude to the deepening of the channel at the mouth of the Mississippi, through the training of the river by jetties and banks. In consequence, ships of large size may now go up the river (there being plenty of deep water above the mouth), and bring down grain cargoes, without the expense and inconvenience of transhipment; thus reducing the freight of corn to this country. This great improvement is the work of Captain Eads. A somewhat similar improvement was the blowing up of about 50,000 tons of rock from the bed of the river, at the narrow pass of Hell's Gate, near New York. It is to be hoped that these good examples may spur our friends on the Continent to improve their harbours, so that large channel boats may cross with comfort to the passengers, thus avoiding the excessive expense that a tunnel would involve.

Great improvements have been made in the illumination of

Lighthouses by oil lamps; a light equal to 13,000 candles has been produced by Mr. Douglass, of the Trinity House, and now two such lights will be placed one above the other, where required.

The Electric Light has made such numerous and rapid strides that it is impossible even to notice its various applications; but on the one hand the lighting by Dr. Siemens of four miles of dock frontage at the Albert dock of the London and St. Katherine Dock Company, together with the railway behind the warehouses, and the warehouses and ships themselves, and on the other hand the elegant and steady domestic light of Mr. Swan, are excellent examples of the two extremes in this department. I believe we shall have the pleasure of closely observing the Swan light during our visit here. The lighthouse electric light is also a noble application of the great power of a single electric light on the arc principle. The most powerful electric light in the world is situated near here on the coast, between the Tyne and the Wear. It is possible, and even probable, that one of the great uses to which Electric Force will be applied eventually, will be the simple conveyance of power by means of large wires; and as a higher percentage of efficiency is gradually being realised, this method will become more economical. I may mention that 60 per cent. has already been obtained.

You may perhaps think that I have delayed too long the mention of the extremely valuable invention of Messrs. Thomas and Gilchrist, by which a very large field of ironstone is now, for the first time, made available for the purposes of making good steel by the Bessemer process. It is an invention that bids fair to make very considerable alterations in the steel-making trade, and in the hands of Mr. E. Windsor Richards it has been made a great success, whilst in Germany there are also several works using the process largely.

Mild steel is now being used to a great extent for the construction of steam boilers as well as of ships, and in steel castings for a variety of purposes, such as spur wheels, frames of portable engines, manhole door-frames, &c., &c.

Amongst the uses to which steel may be put (and, as I think, with advantage) is the manufacture of steel sleepers in place of wood. I trust steel will soon be put to such use in this country, as it would

have the effect of creating a demand equal to that for rails; and it is a very encouraging fact that there are now, or rather there were already, when I was at Dusseldorf in 1880, 70,000 tons of iron or steel railway sleepers in use in Germany. Mr. Webb, of Crewe, has exhibited a very promising arrangement of sleepers and fastenings, to be made either of iron or steel. I think steel sleepers should also be used for tramways.

If now some clever ironmaster could only accomplish the task of making a good "street pavement" of cast iron, the increased demand for pig metal would be enormous; and I do not think we are very far off from seeing it done. It has nearly been accomplished already, by several different modes of construction; and there are very many streets where the luxury of wood pavement (which wears very rapidly) cannot be afforded, and where macadamising will not stand the wear and tear of the heavy traffic.

The use of ingot steel, or very mild steel, for making tin plates is now an established thing, and manufacturers are now taking this metal for making large tinned sheets, up to 7 ft. by 3 ft.

The making of casks by machinery, cheaper and better than those made by hand, is now an accomplished fact by Mr. Ransome's machines. The casks are exactly alike in capacity (which hand-made casks are not), and are very much liked by the wine-growers. There are twelve factories already established abroad, some turning out 2000 to 3000 casks a week. This is a good case of English invention taking the lead in a manufacture.

It is a satisfaction to know that at last we have a watch manufactory in England, as well as three small-arms manufactories.

The manufacturing of ordinary doors and windows by machinery, I am sorry to say, has been pretty much absorbed by Sweden and Norway, where of course they have certain facilities in the raw material, and in water-power.

Amongst good mechanical appliances that have been proved to be highly valuable to the civil engineer may be mentioned the excavating machine, which answers well for certain soils and situations, though not for all; and the dredger of Messrs. Bruce and Batho, for excavating from the inside of piers in water. A

good example of this machine we shall have the liberty of inspecting at Messrs. Hawks Crawshay and Co.'s works, any day during our visit here; this machine lifts 10 tons of stuff at a single lift.

In manufacturing chemistry, which, with its numerous mechanical appliances, is much indebted to mechanical science and engineering, great advances have been made during the last dozen or twenty years.

Aluminium has been brought into practical use to a large extent, being at once a very light metal and a very cleanly one. "Anthracine," obtained from coal tar, has been manufactured largely for the purpose of producing the various brilliant dyes now so common. New materials for making candles have been manufactured, in some cases by purely mechanical means, such as boiling together for some hours, at a pressure of several hundred pounds per square inch, neutral grease and water, when the water takes up the base, viz. glycerine, and leaves the grease as an acid grease. This same effect has been noticed in some steam boilers, where the same water, without admixture of fresh, has been used over and over again with surface condensers.

Carbolic acid has proved itself most valuable in many ways as a disinfectant, and particularly for washing wounds in the field of battle and in hospitals; many operations would be considered most dangerous without it. That other aid to surgeons, chloroform, is now better understood, and largely used in painful operations.

On the other hand the means of destruction have been greatly strengthened of late years; and gun-cotton, dynamite, lithofracteur, and nitro-glycerine, have been made to do wonders in blasting rocks and destroying an enemy's works. These grand effects have quite eclipsed that humble little instrument the "fog signal," which I introduced many years ago for *saving* life.

Then again large rotating chemical furnaces have been introduced; and improved glass furnaces,—particularly "Tank glass furnaces," in which the batch is put in at one end, and the working holes are towards the other end—have cheapened the actual production of glass, and are being worked largely on the Continent, and to some extent in this neighbourhood. Toughened glass has made some

progress for certain purposes. Besides the improved and extended use of glass in lighthouse illumination, it has again been pressed into our service for other purposes, through our greatly extended knowledge of the laws of optics. Spectrum analysis has become of practical use, and photographs of the various Frauenhofer lines in the spectrum have been taken, as permanent records of each experiment. That such extended knowledge should have been developed by that one little instrument, the lens, is but natural; for the lens is at once the means by which we discover the extreme magnitude of some portion of the infinite works of the Almighty, in the architecture of the heavens, and by which we appreciate to some extent the extremely minute markings of a diatom, that cannot be seen with the naked eye. At the same time we feel sure that there are other markings still smaller, as every increase in the power of the microscope has always rendered visible some markings still smaller than the last; and in like manner has every increase in the power of the telescope developed more worlds and suns far away from our system, and beyond our "milky way."

An approach to the infinite in minuteness, and to the infinite in magnitude and distance, is thus furnished to us by one instrument alone.

There is but one further observation that I will venture to make, (though I fear I must already have wearied you somewhat with what I had intended should be a very short address), and it is this. When one looks back upon the goodly list of clever men and benefactors of the human race, who have lived, say, during the last hundred years, one is sometimes tempted to wish that more of those scientific men, who have had the most brilliant ideas, and been our greatest discoverers, should have striven to carry out their discoveries into practice. For instance, take Faraday's beautiful discoveries in electricity (I well remember as a lad seeing the first spark from a magnet): it was, in a manner, left to Sir Francis Ronalds, Professor Daniell, Professor Wheatstone, Mr. Fothergill Cooke, Dr. Siemens, and others, to develop from those discoveries the "intelligence wires" and "bands," that now encircle the earth, and unite nations, and do so much to prevent misunderstandings.

It is fortunate that other men, some of them scientific, but others more purely practical, have been actively alive in following up their ideas in a useful form: as for instance James Watt and Dr. Black in reference to the expansion of steam, and the theory and measurement of latent heat; Dr. Cartwright and Samuel Hall in reference to surface condensation; Woolf and Edwards in reference to economical steam engines; Trevithick, who made the first English locomotive, and carried out high pressure admirably for the time in which he lived; Telford, Smeaton, Brindley, Murdock, the Duke of Bridgewater, Henry Maudslay, Babbage, Richard Roberts, Armstrong, Bessemer, and a host of others, never forgetting him whose centenary you have so lately commemorated, George Stephenson, without whose inventions men and materials could not have been brought together, so as to render it possible for "manufacturing" to be carried on in the most economical manner, and on the largest scale.

It is gratifying to know that the engineering profession has not been forgotten when honours have been conferred on distinguished men; and amongst others may be named Sir William Fairbairn, Sir John Rennie, Sir Peter Fairbairn, Sir Charles Fox, Sir William Armstrong, Sir Joseph Whitworth, Sir Henry Bessemer, Sir John Hawkshaw, Sir John Coode, Sir William Thomson, Sir Joseph Bazalgette, Sir Charles Hartley, Sir Charles Bright, Sir James Ramsden, Sir John Anderson, Sir George Elliot, Sir Daniel Gooch, Sir Henry Tyler, Sir Samuel Canning, Sir Edward Reed, and Sir Frederick Bramwell.

With many noble examples before us, some of whom I have named, and with signs of an improvement in many branches of commerce, I do trust that the latter part of the present century will, with somewhat greater exertion of thought and enterprise on our parts, be marked, not only by numerous small improvements, but by many substantial inventions for the good of mankind.

Mr. JAMES ABERNETHY had no doubt that the members would join with him in returning their best thanks to the President for his very lucid and practical address; which contained not only an able *résumé* of the advancement made in mechanical science up to the present day, but also valuable suggestions for its future progress. He would move a vote of thanks to the President; and trusted that the address would be printed, and added to the Transactions of the Institution.

Sir FREDERICK J. BRAMWELL begged to second the motion that had been made by the President of the Institution of Civil Engineers. It had struck him in listening to the address, that the President had contrived, in the course of a few short minutes, to give one of the most admirable summaries of the progress of engineering and scientific invention applied to the purposes of life, which it was possible for any one to give with the same brevity and conciseness. He had said to himself, "I wonder what can be said as to the progress that has been made in the short time which has elapsed since we were last in Newcastle;" and he had been astonished, as each paragraph was read, to find how much could be said, and truly said, as to that progress, especially in mechanical engineering. He was sure they would all concur in carrying the vote of thanks that had been proposed by the President of the Institution of Civil Engineers.

ON THE TYNE
AS CONNECTED WITH THE HISTORY OF ENGINEERING.

By Mr. I. LOWTHIAN BELL, F.R.S.

Froude, the historian, leads us to infer that in his opinion mechanical engineers attach more than due weight to the assistance afforded by their labours to social progress. Justin Macarthy, commenting on, without assenting to, this proposition, observes it has been maintained that the improvements effected by modern engineering are not entitled to take rank among the genuine triumphs of the human race; chiefly on the ground that there is nothing in them which might not have been expected from the self-interested contrivings of an inferior animal nature.

It would not indeed appear that the last-named author applies the language of exaggeration to the expressions of the historian; for in "Short Studies on Great Subjects" Froude thus speaks of the achievements of modern engineers:—"The steamship and the railway, the electric telegraph, and the infinite multitude of kindred machineries, may easily enough be evolutions of qualities of which we perceive the germs in many creatures besides the apes. If these indeed are our last and sublimest triumphs; if it is in the direction of these that the progress of the race is to continue; then indeed I can be content to look back with tenderness on my hairy ancestry. Instead of 'a little lower than the angels,' I can bear to look on myself as a little higher than the apes, and Pickwick shall be as beautiful as the 'Tempest,' Herbert Spencer more profound than Aristotle, and the electric cable of greater value than the prophecies of Isaiah or the Republic of Plato."

It is possible that there has been, on some occasions, a tendency to glorify beyond their legitimate dimensions the mechanical improvements of modern civilisation. If this be so, it has probably

been the work of those who, unmindful of what has been realised by the philosophy of contemplation, have given undue prominence to the philosophy which expresses itself in mechanical action.

On the other hand it is equally possible that the offspring of mechanical science has been exposed to "angry questioning and some fierce disparagement" by writers not sufficiently conversant with that philosophy, the close study of which preceded many important discoveries of modern engineers.

There are, no doubt, many highly ingenious mechanical contrivances which have attained their present state of high development by such slow and imperceptible degrees, that we can scarcely claim for them the exercise of a very much higher mental organisation than that which Froude appears to think has sufficed for their discovery.

It is not however the sum of "the infinite multitude of kindred machineries" that the writer would alone regard, in endeavouring to estimate the debt due by modern progress to mechanical science. It is rather the large proportion of this multitude that has been placed at our disposal during the brief space of one lifetime, or at most in that of two, which commands our admiration—more perhaps than the author of "Short Studies on Great Subjects" has thought to be merited.

Many ages after the period of the ancient philosophers referred to by Froude, the distaff and spindle, probably the simplest form of spinning machinery ever known to the human race, continued to be the only means employed for the purpose for which it was designed. He tells us indeed himself of Carlyle having seen it at work in the country of his birth; and from its general use in South Italy forty years ago, one might have fancied that the distaff furnished the looms with all the yarn required for clothing the Neapolitan people. Although the spinning-wheel of our grandmothers was a great step in advance of the distaff and spindle, it is so immeasurably behind the inventions of Hargreaves, of Arkwright, and of Crompton, as scarcely to form a halting-place between the spinning, possibly of prehistoric times, and that of our own day: which latter is the growth of the last hundred years, and was chiefly elaborated during a much

shorter period of time. Surely there must have been some influence at work during the last eighty or hundred years, which had previously failed to excite the brain of an inferior animal nature, although prompted by "self-interested contrivings," from the days of Isaiah to those of Shakespeare.

Electricity and magnetism are words adopted from that language in which Plato and Aristotle taught; and the existence of the agencies they designate had been recognised probably centuries before the birth of these illustrious men, now more than 2000 years ago. Yet how little was known of either of these subtle agencies, beyond the power possessed by the one of attracting light bodies, and by the other of drawing iron towards itself; until the profound studies of physicists, almost within the last fifty years, embodied the properties of both in the electric telegraph, regarded and spoken of by Froude as being capable of evolution by qualities of which we perceive the germs in many creatures besides the ape.

Of what avail was the invention of Hero of Alexandria, made 120 years before the Christian era, until Black's discoveries on latent heat, made after the middle of the last century, gave us in the hands of James Watt the steam engine—the precursor of steam navigation and of railway locomotion, which are also included by Froude in his remarks on the work performed by mechanical engineers in modern times.

Without having a single word to utter in disparagement of the studies so highly extolled and so justly cherished by Froude, engineers are entitled, the writer would submit, to make a claim for having laboured in a more elevated sphere than that assigned to them by this authority. Some of their improvements, ending in great results, may no doubt resemble the spontaneous and slow growth capable of being conceived in minds of moderate pretensions. On the other hand, they can point to discoveries which have been founded on an intelligent appreciation of the profound researches of men, whose mental stature will bear comparison with that of any other class.

It is not however on the general progress of mechanical science, or its dependence on the interpreted laws of nature, that the author

ventures, at the request of the Council, to address upon the present occasion the Institution of Mechanical Engineers. He has been invited, as a native of the town in which the Institution is assembled, and as one somewhat conversant with the industrial history of the neighbourhood, to collect a few facts, so that members may judge of the assistance the district has rendered to that branch of practical science which it is their more especial province to cultivate.

Had our ancestors—not the very remote ones mentioned by Froude, but even our grandfathers—recognised the value of such combinations as those of which the Institution itself, in point of utility and success, is a very conspicuous example, the writer's task would not have been surrounded with much difficulty. The Transactions of such a Society would, in all probability, have afforded him an easy access to all the information he required; and his duty would have been confined to condensing the facts they contained into the dimensions of a suitable paper. Such facilities, as all know, are not at his command. Descriptions of mechanical and other improvements, in our manufactures and appliances, are either disseminated in different and often very unlooked for places, or else there is no record whatever of their original introduction and development.

If anything needs to be said respecting the position occupied by the applications of mechanism in the neighbourhood of Newcastle, anterior to the commencement of the present century, it will be to contrast their almost complete absence with what now meets the eye at every turn. At that period Northumberland and Durham were but little removed from the condition of a purely agricultural district; and in those days the cultivation of the soil, here or elsewhere, had received but little attention from the mechanical engineer. The land was ploughed and harrowed much in the same way as it had been for many centuries. It is of course otherwise at present; indeed a corn and cattle producing country would run some risk of soon reverting to its pristine state of wilderness, were it not for the assistance which mechanical science has afforded it in recent days.

The chief exception, eighty years ago, to the rural character of the scenery on the banks of the Tyne was the coal mining in their vicinity, and the coal shipping which took place on its shores. Indeed

within the writer's own recollection, in many places where mounds of slag and cinders now deface the earth, and vapours almost efface the sky, there were fertile fields and hanging woods.

In the first year of the century the output of coal, instead of being 35 millions of tons or thereabouts as it is at present, was represented by $2\frac{1}{2}$ millions. In 1810, according to Robert Hunt, it required the labour of 3568 persons to work each million tons; whereas, in 1863, 22,154,000 tons were obtained by 2135 men and boys per million tons—a sufficient indication of the extent to which machinery has aided the mining interests of the district, and of the general improvement in colliery arrangements and management. The means required for reaching the coal, for extracting it, and for raising it to the surface, together with the large quantities of water which are often encountered in the workings, necessarily involve the expenditure of a vast amount of mechanical force.

If we open the work of the German author Agricola, *De Re Metallicâ*, written in Latin in the year 1556, and then consult the "Archæology of the Coal Trade," published by our late townsman Thomas John Taylor in 1852, we shall perceive a further illustration of that stationary condition of mechanical science, which has already been referred to in connection with other branches of industry, and from which we only broke away within the last hundred years or thereabouts. Judging by the illustrations in both books, the mining engineer of the beginning and middle of the last century might have handed over to his draughtsman the work of Agricola, as a guide for the drawings of the machinery employed in the comparatively shallow pits of that day.

So early as 1713 the steam engines, or more properly the atmospheric engines, of Newcomen were erected on the northern coalfield, at Byker, at Washington, and at Norwood, for drawing water; in place of horses or of water power, which hitherto had been in common use for this purpose. At that time the opening and shutting of the steam valves was performed by manual labour, until Henry Beighton, a Newcastle engineer it has been said, by making the engine work all the valves itself, rendered it for the first time a self-acting machine.

It was near the close of the last century before the device of the crank, or of the sun-and-planet wheels, was applied for the purpose

of converting the reciprocating movement of the steam-engine beam into a rotating motion. The first engine of this class was erected near Newcastle by Boulton and Watt, about the year 1784, at Walker Colliery, and continued in action at the works of the Walker Alkali Company until a year or two ago, when it was dismantled. Anterior to that period, the water raised by the atmospheric engine was often made to fall upon a wheel, which in its turn drove the rope rolls for raising the coal.

It is needless to say that, notwithstanding the excellence of our present pumping machinery, mining engineers are only too glad to dispense with its use whenever this can be effected. It frequently happens that the chief influx of water is met with, not in the coal itself, but in the strata lying above it. In such cases the pit is lined with cast-iron segments or tubbing, as it is called, long in use in this neighbourhood, and improved by the late John Buddle, for preventing the water from following down the operations of the sinker. All that is then required is to have sufficiently powerful pumps at work, until a water-tight bed of rock is reached, upon which the lowest tier of metal segments is placed; and these are continued up to the highest level to which the water will rise. By this means the pit shaft is lined with a metal cylinder which keeps the workings dry. It does however happen occasionally that the water rushes into the sinking pit in such volumes, that there is no room for any pumping arrangement of sufficient magnitude to cope with it. Under such a condition of things there was formerly no alternative but to abandon the attempt to reach the coal, and try elsewhere. This, after the outlay of tens of thousands of pounds, meant the sacrifice of nearly all the money which had been spent; but after what has been recently done at the Whitburn sinking it is unlikely that such a sacrifice will occur again. By means of M. Chaudron's system, an enormous boring tool, the full size of the pit, is made to pierce the water-bearing strata by motion communicated from the surface. When this has been done, and a sound impervious foundation reached, a water-tight cylinder is let down, the internal water is pumped out, and the sinking operations are continued on the ordinary method.

Although not strictly connected with the subject of coal, the fact may be mentioned of the Diamond Rock Boring Company having just completed a perforation or narrow shaft for the writer's firm at Port Clarence. Its diameter is 16 in. at its lower extremity. The depth is about 1200 ft., and the hole itself is intended to raise in the form of brine a bed of salt, which has there a thickness of about 80 ft.

The proper test for ascertaining the excellence of a steam engine is the amount of duty performed for a given weight of coal consumed. Measured by this standard, we cannot claim for our district a very high position. For many years the necessities of the coal trade caused many thousands of tons of good fuel to be annually thrown over the spoil heap; hence it was evidently no gain to employ a more expensive class of machinery, to save fuel which had no commercial value. It is true that this waste has long been discontinued; and practically every ton of coal now raised in our Northern coalfield is applied to some useful purpose. Nevertheless it does not appear that the extra expense and complication involved in employing condensing engines, or other means of economising heat, are met by the saving in fuel when taken at its actual market price. In a paper read before the Mining Institute, Mr. J. B. Simpson gave particulars of a pumping engine of the Cornish type erected near this town. The value of the coal burnt did not much exceed £300 per annum; but the additional cost of the machinery, as compared with that of a non-condensing engine of the same power, would be close on £3000. Now admitting one half more fuel to be required by the latter, it seems clear that the margin of economy was insufficient to cover the increased outlay and cost of maintenance.

Of machinery employed in raising the produce of our mines to the surface we have some striking examples, by means of which 4 tons of coal, along with 9¼ tons for the weight of cage, rope &c., in all 13¼ tons, are brought to bank from a depth of 300 fathoms in about 50 seconds.

Vast as was the destruction of small coal, which fed our "fiery heaps" in years gone by, the actual loss is far surpassed by that

going on at the present day at the coke ovens in the North of England. It is estimated that the annual make of coke in the district is about $4\frac{1}{2}$ million tons, for which $7\frac{1}{2}$ million tons of coal will be required: so that we may calculate on 3 million tons of inflammable gases being evolved in the process. Now supposing that as much as one-third of the heat given off by the combustion of this enormous volume of gas is devoted to "burning" the coke, we have left at our disposal that afforded by the remaining 2 million tons. This gas, as many know too well, escapes as lurid flame from the top of the ovens, defacing the country for miles around with black smoke and sulphureous exhalations. Of late years some attempts, entirely successful as far as they go, have been made to apply a remedy to so large and wasteful an expenditure of heat—so large in point of amount that there is usually no difficulty in obtaining from it sufficient steam for performing the mechanical work of the colliery.

The mechanical agency employed in freeing our mines from the so-called fire-damp, which often escapes from the coal in overpowering volumes, was until recent years of the simplest description. It consisted in establishing a current of air all through the intricate workings, by using one of the pits as a chimney to a large furnace kept burning at the bottom, while fresh air descended through another shaft. In many collieries the furnace has been superseded by gigantic machines known as ventilating fans, and driven by steam power. By one of these machines upwards of 200,000 cub. ft. of vitiated air is occasionally withdrawn in each minute, its place being supplied by pure air drawn from the surface. In this way the inflammable gas, under the usual conditions of its emission, may be diluted so as to render it incapable of explosion. At the face of the coal however, where the miner is pursuing his labours, and indeed often for a considerable distance behind him, this point of safety may not have been attained.

Against the peril of explosion therefore the workman depends on the safety-lamp, which not only protects him from, but warns him of, the danger when it arises, thus deserving the motto attached to it by our Mining Institute of *Moneo et Munio*. The late Matthias

Dunn describes this instrument as a *little machine;* and its mechanical construction, along with some of the circumstances attending its invention, leads the writer to give it a brief notice in this paper. After some terrific explosions which occurred about 1814, Sir Humphrey Davy was invited to visit Newcastle, to assist the coal-owners with his advice in respect to the then system of ventilation. Unable to suggest any improvement in this direction, the great chemist applied himself to a close investigation into the nature and properties of the firedamp itself, which he communicated to the world in his admirable researches on flame. These labours revealed the fact that a wire gauze is able to prevent the passage of flame through its interstices: so that, in the event of an inflammable mixture exploding in the inside of the lamp, communication of the flame to the outside, under ordinary circumstances, is shut off.

The writer cannot refrain from alluding to the most disinterested and very valuable services, rendered by a distinguished north-countryman to Davy during the course of his enquiries. As incumbent of the parish of Heworth, the Rev. John Hodgson was too familiar with the appalling scenes consequent upon the "firing" of a pit. He had moreover already made himself acquainted with many circumstances connected with the evolution and properties of fire-damp, which were duly communicated to Davy at the beginning of his labours. The day after the first Davy lamp was received, Hodgson descended one of our dangerous collieries, and with a heroism which has never been sufficiently recognised, proved that an explosion might take place inside the lamp without inflaming the death-dealing atmosphere in which the daring experiment was tried.

Desirable as it is, on many accounts, to supersede the manual exertion of the miner by mechanical means, it cannot be said that the question has up to this time, in the matter of extent, passed much beyond the limits of experiment. Very good machines, by Walker and others, have been contrived for the purpose of working coal, as well as the ironstone of Cleveland. Much of the attendant labour however requires human agency for its performance: such as the frequent change of position of the machine itself, and more particularly the filling of the produce into the

wagons. The margin left for economy is thus not a large one; and hence the actual saving hitherto effected has not been of a very encouraging nature.

It is not however to the mere extraction of the coal that the agency of the mechanical engineer is confined. The produce of the pits has to be conveyed by land to the place of shipment or to the point of consumption, at an expense occasionally equal to or exceeding the cost of bringing it to the surface. The transport of coals, as performed until the beginning or middle of the seventeenth century, viz., in sacks on the backs of horses, or in wagons drawn along the indifferent roads of that period, placed a mine, situated at even a very moderate distance from the river, at a great disadvantage. Tracks of wood were then laid down, it is scarcely known where in the first instance, but, looking at the antiquity of our coal workings, more likely in this neighbourhood than elsewhere; and this constituted the germ of that kind of locomotion which has wrought so immense a change in the social history of our globe.

It is supposed that the first idea of forming the railroad of cast iron occurred in 1738; but the wagons in use on the wooden roads being too heavy, or the iron rails too light to carry the load, it required thirty years before it struck any one to diminish the size of the one, or to increase the weight of the other. Such a rate of progress would appear indeed to justify the belief that the development of mechanical engineering did not exceed the "contrivings" referred to in the opening remarks of this paper.

For forty or fifty years the horse on the level, and on uneven ground the steam-engine by means of ropes, continued to labour on the iron roads in conveying coal to its point of destination; when a crude idea of Trevithick's was taken hold of by Mr. Blackett, of Wylam near Newcastle, who, with the aid of his engineer, William Hedley, constructed the first locomotive which ever did any work worthy of the name.

In a small cottage, situate on the railway along which Mr. Blackett's engine ran, but some thirty years before its appearance, George Stephenson was born. To his ingenuity, and particularly

to his confidence in the then improved powers of the engine, the world owes a good deal in respect to the period at which it received the gift of the locomotive, as we see it at the present day.

First at Killingworth, for the use of the colliery there, and next at the Walker Iron Works for sale, locomotive engines were constructed under his superintendence. These early engines, according to information left by the late Nicholas Wood, and given to the writer by his son, Mr. Lindsay Wood, cost £500, and weighed, exclusive of the water tank, 6 tons. The boiler was 8 ft. long and 4 ft. 2 in. in diameter, with a single tube. On a level road, and with a consumption of 16 cwt. of coal per day, these engines, on the Hetton colliery railway, could draw twelve wagons of coal, weighing, all included, about 48 tons, at the rate of four miles an hour. Upon this slender foundation of experience, gained from our collieries and from the first public railway in the world, the Stockton and Darlington, Stephenson was able by his force of character to build an argument, which determined the adoption of the locomotive on the Liverpool and Manchester line. An experimental engine, the famous Rocket, was built within a stone's throw of this room, by means of which the then unheard and undreamt-of speed of nearly thirty miles an hour was attained.

From the diminutive dimensions of this early attempt, the locomotive grew, under the fostering care of the Stephensons, father and son, of the Hawthorns in this town, and of other firms elsewhere, to a machine which is a marvel of compactness, combined with mechanical strength and power. By means of it something like 1000 tons of dead load can now be drawn on a level, at a speed of 25 to 30 miles an hour. For this extraordinary amount of duty we are indebted to the multitubular boiler, suggested by Henry Booth, and first successfully applied by the Stephensons in the Rocket engine.

In less than twenty years after the celebrated trial on the Liverpool and Manchester Railway, the London newspapers were delivered by the locomotive in Edinburgh on the evening of the day of publication. It needs nothing more than to recall the existence of the many many thousands of miles of railway at work in different quarters of

the globe, as an evidence of the vast changes which have sprung out of the northern coalowner's attempts to economise his cost of transport.

In connection with the development of the railway system, we may claim for Newcastle the merit of originating some minor, although not unimportant inventions. The late Benjamin Thompson first cast case-hardened railway wheels, afterwards improved by William Losh, the inventor subsequently of the same article in wrought iron; and the first malleable iron rails, as we now understand the word, were rolled at the Bedlington Iron Works by John Birkinshaw of that place.

Cheap as transport has been rendered by the locomotive engine, conveyance between distant places is, and in all likelihood will continue to be, more economically performed by sea. The Tyne, it must be admitted, has done a fair share of the work in cheapening the cost of conveying merchandise by water.

It was well known for more than half a century that mechanical engineers could construct a wrought-iron fabric, capable of resisting a pressure of above 100 lbs. on the square inch. It was also known that such an iron fabric possessed a buoyancy in water far exceeding that of a wooden fabric of the same external dimensions: while the latter would have fallen to pieces under less than one-tenth of the pressure that could be borne by the iron. Nevertheless, the unwillingness of shipbuilders to adopt the new material, and the prejudices of shipowners, greatly retarded the arrival of that day when every ship on the Tyne and elsewhere in the United Kingdom would be constructed of iron instead of wood.

Opposition to the change which has since effected so much for naval architecture was not confined however to the builder and owner of ships: the freighter himself joined in the outcry against the new material, it being stipulated that certain cargoes, tea and rice amongst the number, should be carried in wood and not in iron bottoms. This is the more remarkable, from the circumstance that it subsequently happened that the employment of iron and not of wooden vessels was a condition of charter for carrying the very commodities in question.

It is just about forty years since John Coutts, following an example set elsewhere, laid down the keel of the first sea-going iron vessel built on our river; but he died before seafaring men were convinced of the sagacity of a change, which has placed this country in the very front of shipbuilding countries. It is only rendering justice to those who thought differently, to remember that other circumstances, besides those alluded to, have greatly favoured the substitution of iron for wood in the construction of ships. The application of the screw, which throws the whole strain of propulsion on a very small area of the fabric, demanded immense powers of resistance, much more easily obtained by the use of metal than of wood. Again, the invention of compound engines, by which nearly one-half the fuel formerly used was saved, pointed also in the direction of iron shipbuilding. Still, as our townsman, Mr. C. M. Palmer, M.P., remarked in a paper he read in Newcastle in 1863, he found it difficult to convince nautical men that a steam collier costing £10,000, and burning coal all the way from the Tyne to the Thames, could compete with a sailing vessel of the same capacity, costing one-fifth of that sum, and paying nothing for the wind which drove it from one port to the other. Resistance to Mr. Palmer's views however was no longer possible after he had proved that instead of about a dozen voyages in the year his screw collier performed nearly sixty, and that the saving in labour far more than compensated for the greater first cost, and for the value of the fuel consumed in doing the work.

In the communication referred to, Mr. Palmer estimated that in the year 1862 the following tonnage of iron vessels had been built on the three northern rivers:—

	Tons.
On the Tyne	32,175
Wear	15,608
Tees	9,660
	57,443

For these vessels 28,660 tons of iron had been consumed, and 8,110 men employed, exclusive of those engaged in building the engines.

Mr. Palmer, by his language, evidently anticipated a considerable extension of iron shipbuilding in the district referred to; but it may

be questioned whether his expectations rose to the figures realised in last year's operations.

In 1880 there were built on the Tyne	130	vessels of	139,843	tons
„ „ Wear	65	„	92,176	„
„ „ Tees	25	„	31,756	„
„ at West Hartlepool	30	„	44,500	„
„ „ Whitby	6	„	9,526	„
	256		317,801	

As an example of the increased economy in construction and the greater efficiency of screw steamers at the present time, when compared with those built a few years ago, the writer may quote the following figures given him by a large shipowner in the North of England. In 1866 this gentleman bought an iron screw steamer, capable of carrying 700 tons of cargo with a consumption of 16 tons of coal per 24 hours, for £14,000. In 1881 he purchased another vessel, carrying 3100 tons of cargo with 17 tons of coal burnt in the 24 hours, for £28,000. This means that the price in the year 1881 is only 45 per cent. of what it was fifteen years ago for the same capacity; and that the consumption of coal is only 24 per cent. of its former rate, for a similar amount of duty performed.

The large quantities of the small coal, already spoken of as having been thrown aside in former times, induced the mine owners to offer it at a price little more than the cost of transport. This did not exceed 1*s.* 6*d.* per ton delivered into craft on the river; and hence arose on the banks of the Tyne different branches of manufacturing industry, in which fuel constitutes an important element of cost. Among these, iron is the most deserving of notice upon the present occasion, not only on account of its extent, but from the important service a cheap supply of this metal renders to the mechanical engineer.

It is true that we cannot claim for the Tyne the same relative standing now, as an iron-making locality, which she occupied some thirty years ago. The change has arisen not so much from any decadence on the part of our river in point of production, as from

the extraordinary wealth of ironstone found in the Cleveland hills. This discovery, of recent date, assisted by the resources of the Durham coalfield, has raised Cleveland into the position of the largest iron-making district in the world.

The cheapness of fuel and the easy access to the Thames from the Tyne were probably the causes which induced Ambrose Crowley, a citizen of London, to establish ironworks in 1690 at Winlaton near Newcastle, where different articles, including nail rods made by the slitting mill, were manufactured.

Iron was a very much scarcer metal for long after the days of Crowley than it is in our own times. So late as 1740 the make of pig iron in the United Kingdom was only 17,350 tons; and in those days it took a furnace a week to run as much as a modern Middlesbrough furnace does in two hours. So recently as the beginning of the present century, Swedish bars were imported into the Tyne and converted into slit-rods: so that it is not unlikely that Sweden also furnished the raw material for the Winlaton works founded in 1690.

Before the early part of the last century, every morsel of iron used in the arts was drawn under the hammer. To a certain John Hanbury is ascribed the invention at that time of rolling iron plates by means of cylinders. This idea remained without further application until 1783, when Cort patented the rolling of bars by the means suggested by Hanbury. For a long time however the process was confined to making flat or square bars: indeed the writer's friend Mr. Joseph Laycock, of Gosforth, remembers in his youth men working many a long day in forging squares into rounds, probably thirty years after the date of Cort's invention.

The writer recollects the late William Longridge informing him of the elation of his firm at Bedlington, when they succeeded in turning out a boiler plate weighing $2\frac{1}{2}$ cwt.; and long after that day plates weighing above 3 cwt., or more than 3 ft. wide, were charged an extra price, on account of the difficulty attending their manufacture. Now our plate-rollers send out their iron in pieces weighing about 11 cwt., without classifying them as extraordinary sizes.

Pig iron was first smelted on the Tyne at Lemington about the

year 1812. The late Mr. Clayton Atkinson gave the author the particulars of the cost of manufacture, which amounted to 105*s.* 6*d.* per ton. Nearly $2\frac{1}{2}$ tons of coke were used in the operation, equal, all included, to about 5 tons of raw coal, with a make of 49 tons per week from one furnace.

Small rolling mills were erected at Lemington, and by Hawks & Co. at Gateshead, for working up old scrap iron; and larger works were afterwards built by Losh Wilson and Bell, in 1827, at Walker, where the process of puddling iron was first practised on the banks of the Tyne.

Probably no manufacture has, during the last fifty years, made greater advance in the direction of economy than has the iron trade. Previous to the introduction of the hot blast, and partly owing to a very wasteful mode of coking, as much as 10 tons of coal was occasionally consumed in Scotland for the production of a ton of pig iron. Thirty years ago, when the first blast furnaces were built at Middlesbrough, this rate of consumption had been reduced to about 4 tons. After the lapse of a dozen years, by a great increase in the capacity of their furnaces, by the use of more highly heated air than that hitherto employed, and by the application of the furnace gases to the steam boilers and to the hot-blast stoves, the north-country ironmasters had further reduced this to something under 2 tons of coal; while the make per furnace has been increased from 140 to 500 tons per week.

To a Middlesbrough firm, Messrs. Bolckow Vaughan and Co., under the able guidance of Mr. E. Windsor Richards, the great iron industry of the present generation is indebted for its last act of amelioration. This observation refers of course to the successful application of the so-called basic process, by means of which phosphoriferous iron, like that of Cleveland, is capable of being employed in the Bessemer converter.

The rolling machinery of the firm just mentioned has kept pace with the other improvements referred to; for out of one rail-mill driven by two pairs of reversing engines, the invention of our former President, Mr. John Ramsbottom, and representing a power of 8000 horses, above 3600 tons of rails, in lengths of 90 ft., have been produced in one week.

The manufacture of steel appears to have been carried on in the vicinity of Newcastle for upwards of 300 years; first, it is believed, by some Germans who settled at Shotley Bridge towards the close of the seventeenth century. Notwithstanding the cheapness of coal and the convenience of Newcastle as a port for receiving Swedish iron and for exporting the products, Newcastle never attained any eminence as a steel-manufacturing centre. Nevertheless the house of Spencer has distinguished itself by the quality of its products in crucible and other varieties of steel: to which in recent years has been added a large trade in steel made in the regenerative furnace of Siemens.

The elevated range of country situate west of Newcastle contains extensive deposits of the Mountain Limestone, in which are found several metalliferous veins so rich in lead, as to have given rise to a large business in smelting and other works, connected with the treatment of this metal. The most important improvement in this branch of practical metallurgy, for which this district is entitled to claim the credit, is the desilverizing process of the late Hugh Lee Pattinson. In it the discovery that a mass of the melted metal, in cooling, permitted the mechanical separation of pure solidified lead, was made use of in economising the extraction of the silver, which was found to be left behind in the portion remaining longest fluid.

The requirements of the chemical manufacturers on the Tyne necessitate the importation of large quantities of iron pyrites, containing a small percentage of copper. The sulphur contained in this mineral, to the extent of from 60,000 to 70,000 tons per annum, is converted into sulphuric acid for the soda makers; but the iron would be useless unless the associated copper were first removed. The united value of the two metals is such that a large copper-smelting industry has sprung up on the banks of the Tyne, affording thus a valuable instance of interdependence among different and very dissimilar branches of manufacture.

It would be impossible upon such an occasion as the present to do more than catalogue the immense variety of machinery, which is now, and has been from the earliest days of mechanical engineering, constructed in the neighbourhood of the town in which we are

assembled. Much interesting information on this subject was presented to the British Association, at its meeting here in 1863, by Messrs. Percy G. B. Westmacott and J. F. Spencer.

According to a statistical Table prepared by these gentlemen, the earliest constructors of machinery in this neighbourhood were Hawks and Co., who commenced in 1747 a business, still carried on, at Gateshead. The annual value of the machinery turned out, by the engineering firms on the Tyne and its vicinity, was estimated by Messrs. Westmacott and Spencer to amount to nearly two millions sterling in the year 1862. The date of the founding of the house just mentioned proves at how early a period mechanical science on a practical scale found a footing here; and this is further confirmed by what has been done in connection with marine-engine building. The *Comet* was built by Henry Bell on the Clyde in 1812, and was the first really successful attempt in this kingdom to apply steam to purposes of navigation. Within two years of this date the *Perseverance* was launched on the Tyne, designed for the towing of vessels. This was the first time a steamer was applied to such a purpose, and it was done at a time when there were only 17 steamboats in existence.

No description of the progress of engineering on the Tyne would be satisfactory to any audience, much less to one assembled in Newcastle, that did not refer to what has been effected in connection with its development by our townsman, Sir William G. Armstrong.

The fact that the great power commanded by a lofty column of water had been long known without being extensively applied, only adds to the merit of the inventor of the system of hydraulic machinery now associated with the name of Armstrong. As all present are aware, it is not the mere idea of applying the power of gravitation through the means of falling water, but the extreme ingenuity and completeness of the mechanism whereby this idea is carried out into practice, which commands our interest.

Admitting the economy of availing ourselves of a power created, as it were, by the unaided forces of nature, many questioned the

profitable application of hydraulic agency, when it had to be obtained by the previous action of a steam engine. Two important considerations were lost sight of by the mechanical sceptics of the day—the faculty possessed by Sir William Armstrong's principle of storing the continuous energy of a small engine, so as to perform a vast amount of duty at intermittent periods; and the ease with which such duty is distributed at different points, over a long distance from the spot where the power is generated.

It is impossible to refer to more striking examples of these valuable attributes of the hydraulic system than those afforded by the swing bridge over the Tyne, where a massive structure of iron 281 feet long, and weighing close on 1500 tons, is opened and shut in almost a few seconds by a steam engine of insignificant dimensions; and by the application of the same system, as suggested by Mr. T. E. Harrison, for the distribution of power over the large goods warehouses of the North Eastern Railway in this town.

More than twenty years ago the late Emperor Napoleon III. sought to render vessels of war invulnerable by covering them with plates of forged iron, afterwards advantageously replaced, at the suggestion of Mr. C. M. Palmer, by the rolled metal. These, as is well known, have been increased from 4 in. to sometimes 24 in. in thickness; and mills have been constructed at Sheffield able to roll plates of 30 tons weight, instead of those of $2\frac{1}{2}$ cwt. which astonished the Longridges in the earlier part of the present century.

The writer is not aware whether it was the desire to send a shot through the sides of the *Gloire*, the ship built by the French, or to reach an enemy some hour or so before we came within range of his batteries, that induced Sir William Armstrong to turn his thoughts from the peaceful and all but silent action of his hydraulic engines, to the warlike and noisy monsters with which he has also coupled his name.

When artillery has to be carried into action, or even when used from a stationary fort, it is clearly of importance to have the greatest resisting power combined with the smallest weight of material to be moved. The tensile strain capable of being endured by wrought iron is about $3\frac{1}{4}$ times that of cast iron; but the difficulty of applying

the former to ordnance arose from the impracticability of obtaining a perfectly sound mass, and also of bringing the outside parts of a forging into that state of tension which is necessary to the attainment of the full strength of the material, when used in the condition of a hollow cylinder to withstand internal bursting pressure. From these difficulties Sir William Armstrong escaped by his well known system of coil welding: using which he began by making small guns with rifled bores to be carried on the backs of horses, and ended in 1863 by constructing a gun weighing 22 tons, with which he drove a shot weighing 300 lbs. through $5\frac{1}{2}$ inches of solid iron, then through a mass of wood, and finally through a second plate of iron 2 in. thick. At this stage it might have been supposed he had reached a point where the size and weight of the instrument rendered further enlargement impossible, owing to the difficulty of handling so heavy a mass. Since then however guns weighing 100 tons have been made at Elswick, capable, it is estimated, of throwing a shot of nearly a ton weight to a distance of $8\frac{1}{2}$ miles. The range is adjusted by machinery of mathematical correctness, approaching that of an astronomical telescope, and yet of so substantial a character as to be able to withstand the strain of driving the shot, impelled by the explosion of a quarter of a ton of gunpowder, through $27\frac{1}{2}$ inches of solid iron. The energy of the shot, as actually measured, was found equal to 41,333 foot-tons; but this result, it would appear, does not correspond with the energetic impulses of Sir William, who informs the writer that he has a new gun in hand which is destined to receive a charge of 700 lbs. of gunpowder.

A subject which occupies at present a large amount of public attention is the conversion of motion into light and heat by means of electricity, and even the reconversion of electricity so obtained into motion. The writer intends to speak, and this very shortly, of the first mentioned of these purposes only. The objections to the electric light as hitherto used have been its great intensity, and a certain amount of unsteadiness arising from causes which need not here be specified. From both of these Mr. J. W. Swan of Newcastle has relieved it, by means of his carbon filament, enclosed in a small glass globe

from which the air has been exhausted by a Sprengel pump. The preparation of this carbon thread, simple as it is in appearance, has been the result of long and patient research on the part of the inventor, and has proved eminently successful. By passing a more or less powerful charge of electricity through it, a perfectly steady light of any degree of brightness or brilliancy is obtained, and so completely under control that we may look before long for a great extension of electric illumination.

The chemical trade on the Tyne, not only from its extent, but more particularly on account of the large amount of machinery now employed in its prosecution, deserves a brief mention on the present occasion. The section of industry here known by this name is the manufacture of soda and its cognate branches. The quantity of salt decomposed for this purpose is now about 250,000 tons per annum; but the business is one which grew out of small beginnings.

William Losh, the same gentleman whose name has already appeared in these pages, had learnt chemistry under Lavoisier at Paris. He was present in the chamber, as he used to tell the writer, when Louis XVI. returned from his memorable flight to Varennes; and he quitted the French capital when it was no longer safe for an Englishman to remain. He had however learnt enough to induce him, on his arrival at Newcastle, to try his hand, in company with Lord Dundonald, at making soda. Various methods were practised by these early alkali makers; but ultimately W. Losh returned to Paris at the time when Napoleon was at Elba, learnt the particulars of Leblanc's plan, and established works at Walker, which were carried on by himself and his successors for more than sixty years. As an indication of the extraordinary progress of economy in a process still followed in our own times, the author may mention that he has in his possession an old invoice book of the Walker Alkali Company, in which crystals of soda are charged at the rate of £60 per ton, the present price being 50*s.* or 55*s.*

Excepting for the purpose of grinding or moving the materials employed in the operation, the use of machinery was until recently unknown in our chemical works. In order to economise labour, mechanical contrivances have been introduced for furnace work;

and the difficulty of keeping their moving parts in order has been surmounted, even where they are exposed to high temperatures and to the action of corrosive vapours.

As the Tyne and the Wear were, according to the venerable Bede, the first places in this island where glass was used for architectural purposes, so it would appear to be not improbable that it was upon the banks of the former river, that the manufacture of this article of modern luxury and general utility was first introduced into Great Britain. The earliest flasks for containing liquids, and the so-called crown glass formerly used for glazing, owed little of their progress to mechanical contrivances. The only tools worthy of the name were the glass-blower's pipe, and the rough shears for dividing the so-called "metal." As many as 50 million bottles have been made in one year in the North of England, as well as vast quantities of pressed flint-glass: the former owing their more regular form to being blown within accurately fitted moulds. In like manner the large sheets of plate glass, with which we are now so familiar, are first cast on large tables, and then polished by well contrived machinery. More recently Mr. James Hartley of Sunderland suggested the use of rollers for extending glass into sheets, which are now extensively known in an unpolished form under the designation of Hartley's rough plate.

In North Africa the writer has seen the Kabyles engaged in making earthenware, by means of implements not much behind the machinery exclusively used within the last twenty years by the "throwers" in the potteries on Tyne-side. No house in this district, or probably in any other, can compete with Mr. Maling's in the extent to which steam power has been rendered available in this very ancient art. This gentleman writes that he employs 500 to 600 indicated horse power in grinding 150 tons of flints and 400 tons of clay per week: which materials are converted, chiefly by mechanical means, into half a million jars for containing preserved fruits.

A very large trade is carried on near Newcastle in the manufacture of articles of fire-clay, and in making bricks and tiles from the ordinary brick-earth of the neighbourhood. The limits of this paper however do not allow more than to mention that the machinery

employed for both purposes is not inferior, the writer believes, to that in use in other parts of the kingdom.

The extraordinary efforts which have been put forth for the improvement of the navigation of the northern rivers, but more particularly of the Tyne, belong to the civil rather than to the mechanical branch of engineering science. Nevertheless the mechanician has had his ingenuity taxed in providing the means for effecting that which has been done in the direction referred to. The great swing-bridge has been already named; but the great dredger for deepening the stream, and the steam excavator for removing dry land, also deserve notice for the amount of work they perform, under the superintendence of Mr. Messent, the Resident Engineer of the Tyne Improvement Commission.

These remarks on the history of engineering as connected with the Tyne must now be concluded. In reading over these pages, the writer has become impressed with the superficial nature of the descriptions they contain; but this is perhaps inseparable from the character of the duty assigned to him by the Council, who, if that be true, must divide with himself the responsibility of the meeting having been detained by less important matters, and by less severe studies, than those to which the members are accustomed.

ON THE PROGRESS AND DEVELOPMENT OF THE MARINE ENGINE.

By Mr. F. C. MARSHALL, of Newcastle-on-Tyne.

At the Liverpool Meeting in 1872, Mr. F. J. Bramwell, F.R.S., now Sir Frederick Bramwell, Past-President, read a paper before this Institution on "The Progress effected in Economy of Fuel in Steam Navigation, considered in relation to compound-cylinder engines, and high-pressure steam." This paper was most exhaustive in its character, and was followed by a discussion, in which some of our most prominent engineers took part.

Having been asked to prepare a paper for this meeting on the marine engine, the writer naturally turned to what had been laid before the Institution on previous occasions. He found that Sir Frederick Bramwell's paper embraced all the past history and present condition of marine engineering, and to some extent forecast its future. On the same occasion Dr. Siemens, F.R.S., the President for the year, remarked that during the nine years which had elapsed since the first meeting in that city the marine engine had been so far improved, that it consumed rather less than one half the amount of fuel at that former time thought to be indispensable; and that, if nine years later his successor were able to announce a similar step in advance, we should have the satisfaction of knowing that the further discussion of the subject that day had not resulted in "lost energy."

We have now completed the term then defined by Dr. Siemens; and the writer proposes to continue the subject from the date of that meeting, and endeavour to trace out whether any, and if so what progress has been made; further, to consider whether or no we have reached the finality so strongly deprecated by Sir Frederick

Bramwell in the discussion referred to, and if not, then in what direction we are to look for further development.

In his paper Sir Frederick Bramwell gives Tables of particulars of the engines and boilers belonging to twenty-eight steamers of different descriptions, and comprising nearly all the types of engine and boiler now in general use. These Tables embrace the sizes of cylinders, heating and grate surface of boilers, condensing surface, working pressure, speed of piston, indicated power, and consumption of fuel.

The average consumption of nineteen of these vessels he shows to be 2·11 lbs. of coal per I.H.P. per hour. The working pressures range from 45 lbs. to 65 lbs. per square inch, the latter being the highest pressure recorded, while 376 feet per minute is the average piston speed.

The writer has been favoured with data, from thoroughly reliable sources, showing in a similar manner the general proportions of engines and boilers recently fitted to steamers in the mercantile marine. These are shown in Table I. annexed (p. 452). It will be noted that the steam pressures are now much higher, the boilers have less heating surface, and the cylinders are much smaller for the I.H.P. developed; and at the same time the average consumption of fuel is reduced from 2·11 lbs. to 1·828 lbs., or by 13·37 per cent.

A substantial progress is thus shown to have been made during the nine years; and although it does not reach the enormous gain of the previous decade, it is probably as much as could reasonably be expected, since the closer we approach the limit the more difficult will improvement become.

The Marine Engine of to-day is substantially the same in design and arrangement as Sir Frederick Bramwell described it. The compound two-cylinder vertical engine, with receiver, and with two cranks at right angles, as shown in Figs. 1 to 3, Plates 53 and 54, is the most commonly accepted type. It embodies great simplicity in design, great facility—and therefore cheapness—in manufacture; it has few moving parts, is easily handled and tended, is very accessible throughout the working parts while in motion, and is readily repaired.

The single Woolf engine, commonly known as the Tandem Engine, with single crank and fly-wheel, as shown in Figs. 4 to 6, Plates 55 to 57, was originally introduced and developed by Mr. Alfred Holt, and has recently been adopted by some other shipowners, with great satisfaction to themselves. It is still however looked upon with doubt and suspicion as to "unhandiness" by shipowners and their engineers generally, and therefore does not make much progress in numbers as compared with engines having cylinders side by side: and this notwithstanding the undoubted advantage it possesses, of taking up less fore-and-aft space in the vessel, and of having fewer working parts to be looked after.

Next in order of general acceptance to the two-cylinder receiver engine, with cranks at right angles, is that known as the Double Tandem Engine; which consists of two Woolf engines placed side by side, and working two cranks at right angles, Fig. 7, Plate 58. These engines have been extensively adopted for the largest transatlantic steamers, and with great success.

The tandem form of compound engine possesses the great advantage of independence of action, and may therefore be multiplied indefinitely in its application to one propeller. It has long been used in the double form, and last year at Barrow it was introduced to the notice of the Institution in its triple form, as applied to the *City of Rome* (Proceedings 1880, p. 340). So long as it is thought wise to concentrate the propelling power of a vessel in a single instrument, the number of such engines working side by side may be increased indefinitely. The triple or quadruple arrangement of such engines, as will readily be seen, gives great uniformity of strain, and greatly relieves the weight and friction on the crank-shaft, besides balancing all the moving weights. To set against these facts, there is of course the great disadvantage of increased number of parts, always a serious consideration on board ship at sea.

A modification of the Woolf engine, introduced by Mr. D. Rowan * of Glasgow about the year 1861, has three cylinders, one high and two low-pressure, placed side by side, with all three piston-rods attached to one cross-head. It has recently been very satisfactorily

* See correction as to this, p. 481 *infra*.

applied to paddle steamers of large power by Messrs. Douglas Hebson and W. G. Ramsden of Liverpool, as shown in Figs. 8 and 9, Plate 59. In this case the steeple form of engine is adopted; the three cylinders of each engine are firmly bolted both to each other, and to keelsons fore and aft the vessel, thus forming a very solid and substantial base upon which to construct the upper framing. Each set of cylinders is worked by one valve and motion, Marshall's arrangement being used. The three piston-rods are attached to the moving cross-head, and guided in the usual way.

This engine, the writer believes, is a novelty as thus applied. It can be made to weigh no more than the oscillating form; it has given most satisfactory economical results in working; it is easy to maintain, and affords great facility of access to all the working parts for overhauling and repair, when required.

The most recent form of compound engine, introduced into our transatlantic steamships, has three cylinders, one high-pressure between two low-pressure, having an intermediate receiver, and working into one crank-shaft, having three cranks placed at equal angles from each other. This description of engine, Figs. 10 and 11, Plate 60, bids fair to become the favourite one for large powers; several are now at work, and give unqualified satisfaction both as to economy of fuel and cheapness of maintenance. The *Arizona*, of the Guion line, one of the first constructed on this plan, has worked so well hitherto that her owners have since ordered others of greater power of the same description. The *Servia* also, now being finished for the Cunard line, has engines of this kind, with cylinders one of 72 in. and two of 100 in. diameter, and $6\frac{1}{2}$ ft. stroke. Compared with the triple tandem engines of the *City of Rome*, these have only half the number of cylinders, pistons, valves, valve-rods, and appurtenances, to get out of order and keep in repair; while the balance of strains on the main shafting and crank-pins can be readily equalised by adjusting the cut-off of steam.

These three great types of compound engines may be placed as follows, in the order of their general acceptance by the shipowning community.

1. The two-cylinder intermediate-receiver compound engine, Plate 53, having cranks at right angles.

2. The Woolf engine, generally in the tandem form, having the high-pressure and low-pressure cylinders in line with each other, Plates 55 and 56, or occasionally having three cylinders alongside, Plate 59, but communicating their power to one crank. A pair of such cylinders is used sometimes singly, Plates 55 and 56, oftener two pairs together, Plate 58, working side by side to cranks at right angles; recently three pairs together, working to cranks placed 120° apart. The system affords the opportunity of adding yet more engines to the same propeller to an indefinite extent.

3. The three-cylinder intermediate-receiver compound engine, Plate 60, with one high and two low-pressure cylinders, the steam passing from the high-pressure cylinder into the receiver, and thence into the two low-pressure cylinders respectively. The cranks are placed at equal angles apart round the crank-shaft, so as to balance the forces exerted upon the shaft.

These three types may be said to embrace all the engines now being manufactured in this country for the propulsion of steam vessels by the screw propeller. In their leading principles they also embrace nearly all paddle-engines now being built, whether the cylinders be oscillating, fixed vertically, or inclined to the shaft.

The compound engine in fact, in one of these three forms, may now be said to be universally adopted in this country; and the question of the relative value of simple expansion in one cylinder, and of compound expansion in two or more cylinders, which agitated the minds of some of our leading engineers ten years ago, is now practically solved in favour of the latter.

The Marine Boiler of to-day is in all its main features the same as it was ten years ago.

The single-ended boiler, shown in Plate 61, and made with two, three, and sometimes four furnaces, is the simplest form, and, for all powers under and including 500 I.H.P. is the most generally adopted.

The double-ended form, shown in Plates 62 and 63, is largely used. It has been found more economically efficient than the single-ended

form, by as much as 10 per cent. in the writer's own experience. It is generally adopted for engines of large power, but for small powers is inconvenient, owing to its occupying more room lengthwise in the vessel, and also involving two stoke-holds and therefore more supervision. At one time great difficulty was found in keeping the bottoms of boilers of this kind tight. Owing to their length, the unequal expansion due to different temperatures at the top and bottom caused severe racking strains on the bottom seams and riveting—so severe in some cases as to rend the plating for a large part of the bottom circumference of the shell. This difficulty has now been to a large extent got over, in consequence of the greater attention given to the form and direction of the water spaces in the boiler itself, so as to induce circulation of water; the introduction of the feed-water at the top instead of near the bottom; the more careful management now usual on the part of engineers; and lastly, the use of larger plates, welded horizontal seams, drilled rivet holes, and more perfect workmanship throughout.

In boilers having a single flame-box to two furnaces opposite each other, as in Fig. 19, Plate 63, difficulty has been experienced in keeping the ends of the tubes tight, owing to the action of the one furnace upon the other, and the inequalities of temperature induced thereby. This is now obviated by the introduction of a fire-brick division extending just so high as to prevent the current of air, when the door is opened, from striking directly upon the opposite tube-plate.

The modification of double-ended boiler shown in Figs. 20 and 21, Plate 64, is that introduced by Mr. Alfred Holt. It has many decided advantages, but is costly to make. The formation of the two ends into separate fire-boxes leaves the bottom of the boiler free to adapt itself to the variations of temperature to which it is exposed. The separation of the furnaces from the combustion chamber, excepting through the opening afforded by the connecting-tube shown at A, is an advantage in the same direction, and avoids almost entirely the racking strains due to irregular furnace action. The weight of water carried is less, and that of the boiler may also be made less; while the elliptical form of the two ends gives greater steam space.

Figs. 24 and 25, Plate 65, represent a type of boiler largely used in Her Majesty's navy, and very suitable for all classes of vessels where length is available. It is introduced here as a specimen of a highly efficient boiler in regard to weight and power developed. Many examples have yielded one I.H.P. in the cylinders for every 3 sq. ft. of heating surface, under natural draught and with a very moderate height of funnel; and this with a consumption of fuel not exceeding $2\frac{1}{2}$ lbs. per I.H.P. per hour under a working pressure of 60 lbs. With the aid of a steam jet in the funnel, the heating surface per I.H.P. has fallen below $2\frac{1}{2}$ sq. ft. The large water-surface afforded for escape of steam secures almost entire freedom from priming, without the incumbrance of steam domes; and the large combustion chamber allows of the thorough combustion of the gases before their passage through the tubes.

The locomotive type of boiler has lately occupied the writer's attention, with a view to its more definite introduction into marine work. In his recent paper before the Institution of Civil Engineers (Proceedings, 1881, vol. lxvi., p. 87,) Mr. Thornycroft has shown what can be done with it under a forced draught; and how to reduce the weight of boilers and the water in them, as well as how to get a large power out of a small boiler. This form of boiler, Figs. 22 and 23, Plate 65, affords the opportunity of introducing an almost unlimited amount of absorbing surface in the shape of tubes, while the fire-box is in the best form possible for efficiency. The difficulties however, which lie in the way of applying the same principles to steamers going long voyages, are very great. The principal difficulty lies in the necessity of burning a large quantity of fuel in a very limited space and time. This can only be done either by direct pressure or exhaust action applied at the furnace. In other words we must either exhaust the funnel, which will absorb a large amount of power, but would be comparatively easy of application; or our stokers, as is the case with our miners, must work under a pressure of air. The writer would submit for the consideration of the meeting whether this latter is an unreasonable condition of things to contemplate, considering that by so doing we should enormously reduce the dead weight of our boilers and water, and thereby leave room for a corresponding weight of cargo.

The Perkins boiler (described in Proceedings 1877, p. 117 and Plates 15 to 17) may be referred to as a specimen of the tubulous system applied to marine purposes. It must be admitted that the tubulous system has not been a success, as actually worked on board ship; the writer nevertheless submits that this system affords a means of reducing the enormous weight of boilers and water at present deemed necessary, which is well worthy our consideration; more especially as, with increasing steam pressures, this weight must be still further increased, to the serious hindrance of progress, and loss to the shipowner by the displacement of freight-paying cargo.

With regard to the use of steel in marine boilers, the valuable paper read by Mr. Boyd in 1878 and that read by Professor Kennedy at the last meeting have left very little to be said as to the character and use of the material, and the mode of treating it. The writer wishes only to state the result of his experience in the manufacture and working of such boilers, with the view principally of removing the doubt and uncertainty, so freely expressed in the discussion on those papers, and to some extent justified by the failure of the boilers of the *Livadia*. Many steel boilers of sizes varying from 6 ft. to 14 ft. 6 in. diameter have left Messrs. R. and W. Hawthorn's works at St. Peter's since 1877, when the first was made; and in no case has there been a failure of a plate after being put into a boiler, either in the process of manufacture or in working at sea. The mode of working is as follows:—For shell plates, from $\frac{5}{8}$ in. to $\frac{7}{8}$ in. thick, to warm each to a dark red heat before bending in the rolls, having previously drilled a few holes to template for bolting the plates together; the longitudinal seams are usually lap joints treble-riveted, requiring the corners to be thinned, which is done after rolling, as shown in Figs. 35 to 38, Plate 70. The furnace plates, Plates 61, 62, 63, and 65, are generally welded longitudinally, two rings in the length of the furnace, and flanged to form Adamson rings, and at the back end to meet the tube-plate; the back flame-box plates are flanged, as also the tube-plates and front and back plates; and wherever work is put on to the plate it is annealed before going into place. The rivet holes are drilled throughout. In putting together the longitudinal seams of the thicker shell plates, great care is always

taken to set the upper and under plates for the lap to their proper angle before they are bolted together, a point generally overlooked by the practical boilersmith. It will be observed that if this is not done, great strain is thrown on the material, sometimes resulting in fracture; since the plates tend to take the form shown by the dotted lines, Figs. 37 and 38, Plate 70. In two boilers, made in another department of the works, fracture actually did take place while closing up the riveting in four plates $\frac{3}{4}$ in. thick; the riveters having followed the old bad custom, so common in iron boilers, of drawing the plates together when in place, in order to close work which the platers should have closed. The writer suggests that this may have been done in other boilers besides those mentioned. The use of steel for boilers is always recommended by the writer, and in no case has he had cause to regret it.

The question of corrosion is one which is gradually being answered as time goes on; and so far very satisfactorily for steel. Some steel boilers were examined a few weeks ago which were amongst the first made; and the superintending engineer reports, "There is no sign of pitting or corrosion in any part of the boiler; the boilers are washed out very carefully every voyage, and very carefully examined, and I cannot trace anything either leaking or eating away. No zinc is used, only care in washing out, drying out, and managing the water."

This is the evidence of an engineer with a large number of vessels in his charge. His statements could be corroborated by many other engineers in similar positions. On the other hand some of our most prominent Liverpool engineers always use zinc, and take care to apply it most strictly. The evidence of one of them is as follows:—"We always fix slabs of zinc to most boilers, exposing not less than a surface of 1 sq. ft. for every 20 I.H.P., and distributed throughout the boiler. This zinc we find to be in a state of oxide and crumbling away in about three months. We then renew the whole, and find this will last twelve months or more, when it is renewed again. Meantime we have no pitting and no corrosion, but on the contrary the interior surfaces appear to have taken a coating of oxide of zinc all over, and we have no trouble with them." Again many engineers have trouble with their boilers under both systems;

this is due no doubt to some mismanagement, probably the admission of too much air with the feed water. Frequently too the tubes and interior surfaces are destroyed by drops of moisture being allowed to form and dry upon them, after blowing out.

The superheating of steam, notwithstanding its undoubted value in all expansion engines, has practically died out. To some extent the use of much higher pressures has rendered it less necessary; but the practical difficulty in the rapid corrosion of the material of which the superheaters were made, and the restrictions imposed by Lloyd's and the Board of Trade on that account, have mainly led to their abandonment.

The most noteworthy feature of to-day in connection with the marine engine is the demand for largely increased power, to meet the requirements of shipowners for larger vessels and higher speeds. There is a growing feeling amongst them that "speed pays"; and that it is better to ensure certainty of arrival at the port of destination than to save a few tons of coal on the voyage. At the same time it is of the utmost importance that the required increase of speed and power should be achieved, first, with the least possible weight of machinery, water, and fuel to be carried; secondly, with the least possible expenditure of fuel; and thirdly, with safety and efficiency in working, low wear and tear, and cheapness of maintenance.

These points being kept in view, the writer proposes to consider our present marine engine as to its efficiency and capability of further improvement, and then to consider generally in what direction we may look for further development; carefully separating, throughout, the boiler, or steam generator, from the engine, or steam user.

Weight.—The weight of machinery, water, and fuel carried for propelling ships has not had due attention in the general practice of engineers.

By the best shipping authorities the writer is assured that every ton of dead-weight capacity is worth on an average £10 per annum as earning freight. Assuming therefore the weight of the machinery

and water in any ordinary vessel to be 300 tons, and that, by careful design and judicious use of materials, the engineer can reduce it by 100 tons, without increasing the cost of working, he makes the vessel worth £1000 per annum more to her owners. That there is much room for improvement in this direction is shown by the following statement, giving, for various classes of ships, the average weight of machinery, including engines, boilers, water, and all fittings ready for sea, in lbs. per indicated horse power:—

	Lbs. per I.H.P.
Merchant Steamers	480
Royal Navy	360
Engines specially designed for light-draught vessels	280
Royal Navy, "Polyphemus" class (given by Mr. Wright)	180
Modern Locomotive	140
Torpedo Vessels	60
Ordinary Marine Boilers, including water . .	196
Locomotive Boilers, including water . . .	60

In view of the commercial considerations before mentioned, in regard to merchant steamers, these figures confirm the idea that the weight of machinery on board such vessels has not received the attention its importance demands.

The ordinary marine boiler, encumbered as it is by the Regulations of the Board of Trade and of Lloyd's Committee, does not admit of much reduction in the weight of material or of water carried when working. The introduction of steel has reduced the weight by about one-tenth; but it is the alteration of form, to the locomotive, tubulous, or some other type, combined with some method of forced draught, to which we must look for such reductions in weight of material and water as will be of any great commercial value.

The engine may be reduced in weight by reducing its size, and this can only be done by increasing the number of revolutions per minute. It has hitherto been the practice to treat the propeller as dependent upon the size of engines, draught of water, and speed required. This process should be reversed. The propeller's diameter depends on the column of water behind, which is necessary

to overcome the resistance in front due to the properties of the vessel. This fixed, the intended speed will then fix the number of revolutions, which will be found much greater than is usual in practice; and from this the size of the engines and boilers will be determined.

Great saving in weight can be effected by careful design, and by judicious selection and adaptation of materials; also by the substitution of trussed framing and a proper mode of securing the engine to the structure of the vessel (as worked out in H.M.S. *Nelson*, by Mr. A. C. Kirk of Glasgow, Plate 66, and in the beautifully designed torpedo-boat engines of Mr. Thornycroft, Plate 67), in place of the massive cast-iron bedplates and columns of the ordinary engines of commerce. The American engines of the earlier time might also be profitably studied, not for imitation throughout, but to see what can be done towards lightening machinery, and at the same time securing efficiency and durability. Condensers may advantageously be made of plate iron, brass, or copper, due care being taken to guard against galvanic action. The condensing surface needs further consideration; in many cases it is much larger than necessary: in which case massive castings of great weight are required, and large quantities of water carried, which are not really needed.

The same may be said of the moving parts. Solidity and rigidity are great virtues in a stationary engine or machine, and weight is necessary to the locomotive for the purpose of adhesion; but in the case of a marine engine mass and rigidity may, and frequently do, become serious evils. Firstly, unnecessary mass means needless weight to be carried, unprofitable load to be propelled, and the displacement of its equivalent in freight-paying cargo; and secondly, it means rigidity, and the setting up of a state of *heterogeneity* in the whole structure, consisting of ship, engines, and cargo, instead of the *homogeneity* which is essential to a successful working machine. In fine, the hull and engine should be as much as possible one structure: rigidity in one place and elasticity in others is the cause of most of the accidents so costly to the shipowner. Under such conditions mass and solidity cease to be virtues, and the sooner their place is taken by careful design, and the use of the smallest

weight of material (of the very best kind for the purpose) consistent with thorough efficiency, the better for all concerned.

Fuel.—We come now to the question of the consumption of fuel. Referring again to Table I. (p. 452) we see that a considerable saving has been effected in nine years. The averages of Sir Frederick Bramwell's Table and of Table I. stand as in Table II. below:—

Table II.—Comparison of 1872 and 1881.

Item.	1872.	1881.
Boiler pressure, lbs. per sq. in. .	52·4	77·4
Heating surface per I.H.P., sq. ft..	4·41	3·919
Piston speed, ft. per min. . . .	376	467
Coal burnt per I.H.P. per hour, lbs.	2·11	1·828

This shows a saving equal to 13·37 per cent. in quantity of fuel consumed. It is right to mention that the percentage here stated by no means represents the actual saving effected in money value. The coal now supplied to steamers is of very inferior quality compared with that shipped as bunker coal prior to the coal famine of 1873 and 1874. During those years the refuse of the pits and pit heaps, and the poorest of black material, came into use, and this still holds its place firmly as bunker coal; at best unscreened coal is supplied, where the very best screened coal was required prior to 1873. This very materially affects the question in hand, and the writer submits that it would not be unreasonable to take credit for a saving in money value of at least 20 per cent., instead of 13 per cent.

The writer thinks it right to introduce at this point a letter with which he has been favoured by Mr. Alfred Holt, of Liverpool, bearing on this subject, as well as on other matters which will be dealt with presently.

"1, India Buildings, Liverpool, June 18th, 1881.

"Dear Sir,

"In response to your letter of May 27th, I now enclose the form you sent me, filled up with particulars of specimens of two of

my best classes of ships. My vessels run in classes, so there is no occasion to give you particulars of individual ships.

"I do not think that quite so good a result as that shown in the form is generally attained on the average through the fleet; and having commenced lately to allow more steam in the high-pressure cylinders, a less economical performance naturally results. I think I should be able to obtain about 2·3 lbs. per I.H.P. per hour over the whole, and I do not think that I have made anything more than a fractional advance in economy of fuel since 1868.

"The fact of the matter is I have not tried to do so, and I don't believe, so far as my observation extends, that mere economy of fuel is much cared for now; coals, which used to be the greatest, are becoming one of the minor disbursements of a steamer, and it cannot have escaped your notice that some modern steamers, careless of fuel, are actually abandoning both the compound system and high pressure.

"My opinion is, and for many years has been, that the compound system will come to be abandoned. I am endeavouring to feel my way to using the steam in one cylinder only, and so far the results have been encouraging; and I am now engining a 2200 ton vessel on that system. I am also endeavouring to do without a crank-shaft, the forward end of the screw-shaft carrying an ordinary crank with overhung pin. This experiment also, so far as I have got, promises satisfactorily.*

"In my opinion the great improvement of the immediate future is to increase the steam production of our boilers. One ton weight of a locomotive boiler produces as much steam as 6 tons of an ordinary steamboat boiler.

"Of course the solution lies in the possibility of (1) burning more fuel, and (2) taking the heat out of it. It is a difficult problem; a steam blast will not do it, and I am fitting a vessel with a rotary blower, capable of a pressure of about 2 lbs. on the inch, which shall eject air through a tapered blast-pipe up the centre line of an ordinary funnel, so near the top that, before the cold ejected air destroys by its gravity the motive force it has received from the blower, and

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* This engine, and its general arrangement in the ship, is shown in Figs. 29 to 34, Plates 68 to 70, from tracings kindly supplied by Mr. Holt.

so deadens the current, it shall be out of the chimney. At the present time I am more hopeful than confident of the result, but I am convinced improvement in that line is shortly to be looked for. What a gain it would be to diminish the weight of our boilers to one third, which is my aim in the boat alluded to.

"Yours truly,

"F. C. Marshall, Esq., *Newcastle-on-Tyne.*" "Alfred Holt."

This letter the writer considers to be of great importance, coming as it does from one of our most enterprising shipowners, who is at the same time an experienced practical engineer.

It will be noticed Mr. Holt speaks of the coal account as one of the minor disbursements of a steamer. He does not give the ratio which coals bear to the total disbursements, but from other reliable sources the writer finds that, according to the direction of the voyage, it varies from 16 to 20 per cent.—or say an average of 18 per cent.—in a vessel carrying a cargo of 2500 tons. This will represent to-day about £3000 per annum, and in 1872, at equal prices, the cost would have been £3750—showing a saving of £750, equal to a dividend of say 3 per cent. on the value of the ship. Again, the cost of coal per mile run for such a vessel in 1872 would have been at least $16\frac{1}{2}d.$; to-day it does not exceed $13d.$

Viewed from the shipowners' stand-point this may be a minor consideration, but to the marine engineer it is important as indicating progress where progress is difficult; and taking it as such he is encouraged to further effort in the same direction.

Efficiency.—The third part of this question must now be considered, viz. how to increase speed and power with safety and efficiency.

The marine boiler as now made is a very efficient generator. Tables I. and II. show that with an increase of pressure, consumption has been reduced; but if the quantity of steam used be considered, in relation to the increased pressure, it will be seen that the boiler of to-day is little if any more efficient than that of ten years ago: as is shown by the following comparative Table of the calculated advantage due to using steam of the average working

pressure given in Table I., or 77·4 lbs., as compared with the average pressure of 1872, namely 52·4 lbs. The advantage is seen to be 13 per cent., which is almost exactly the same as the actual saving found from Table I.; whence it would appear that our gain in consumption is solely due to higher pressure, and in no sense to increased efficiency of boiler.

TABLE III.

Calculated net Coal and Steam used per I.H.P. per hour, for steam of 52·4 lbs. and 77·4 lbs. pressure above atm.; the same terminal and back pressure being assumed in each case.

	Pressure above atm. 52·4 lbs.	Pressure above atm 77·4 lbs.
Working pressure (total) . . . . . . lbs.	67·4	92·4
No. of expansions	5·15	7·05
Steam used per I.H.P. per hour . . . lbs.	21·00	18·17
Net coal required, per I.H P. per hour . lbs.	1·73	1·501
Ratio of the net coal required, the amount for 67·4 lbs. total pressure being unity. . .	1·00	0·87
Advantage, per cent.	...	13
Coal per I.H.P. per hour, taking 2·11 lbs. as required at 67·4 lbs. total pressure . . .	2·11	1·835
Actual coal burnt, as per Table	2·11	1·828

If the evaporative performance of the marine boiler is to be increased, it must be by one of the four following methods: (1) Increase of heating surface; (2) Better disposition of absorbing surface; (3) The adoption of thinner plates, or of a material having better conductive power for heat; (4) The adoption of a different and better form of boiler as a whole.

The present boiler has an evaporative efficiency of about 75 per cent., and cannot be much improved so long as air is supplied to the furnace merely by the natural draught, due to the temperature and height of chimney. The extent of efficient heating and grate surface is limited, and almost fixed, by the same cause.

To increase the efficiency by one-tenth, or from 75 to 82·5 per cent., would require about double the heating surface, the weight of boiler and water being also doubled. If it were attempted at the same time to increase the pressure, as well as the heating surface, relatively to the coal burnt, the addition would be somewhat less;

thus, were there an increase of pressure from 105 to 150 lbs., then, instead of double the quantity of heating surface, 1·75 of that due to the lower pressure would suffice.

Mr. Blechynden's formula, used in the writer's works for weights of cylindrical marine boilers of the ordinary type, and for pressures varying from 50 lbs. to 150 lbs. total, is as follows:—

$$W = \frac{(P+15)\ (S+D^2L)}{C};$$

$$\text{whence } W = \frac{2S\ (P+15)}{C}$$

if $S = D^2L$, which is a common proportion.

Here W = weight in tons,

P = working pressure as on gauge, in lbs. per sq. in. above atm.,

S = heating surface, in square feet,

D = diameter, in feet,

L = length, in feet,

C = a constant divisor, depending on the class of riveting, &c. For boilers made to Lloyd's rules, and with iron shells having 75 per cent. strength of solid plate, $C = 13{,}200$.

This formula, if correct, and it is almost strictly so, would give the following as relative weights of boilers per sq. ft. of heating surface, for 105 and 150 lbs. total pressure, assuming we wish to increase the efficiency 10 per cent.:—

$$\text{Weight at 105 lbs.} = 105 \times \frac{2\,S}{C}$$

$$\text{,,} \quad 150 \quad \text{,,} \quad = 150 \times 1{\cdot}75 \times \frac{2\,S}{C} = 263 \times \frac{2\,S}{C}$$

$$\text{Hence the ratio of weight} = \frac{263}{105} = 2{\cdot}5.$$

In other words the boiler with the higher efficiency would weigh two-and-a-half times that with the lower efficiency. It appears therefore that increase of efficiency cannot be got to any useful extent by increase of surface, without such serious addition to weight as to render it impracticable, or at least unprofitable.

Next, will better disposition of heating surface, or the adoption of thinner or more conductive material, add to the evaporative efficiency?

It is difficult to see in what way any great departure can be made

from the present arrangement of surface. The introduction of the Fox corrugated furnace is the only step made of late years, and it promises in the future to be an effective form in which to place the material. Hitherto there have been difficulties connected with its use, but these have been in every case due to manufacture, and such as are incident to every new process. They have in no case arisen from the principle of corrugation, which must in time permit the furnaces, the best and most vital of the effective parts of the boiler, to be made of considerably thinner plate; and will thus increase to some extent the efficiency of the boiler. The use of metal of higher conductivity for the flame boxes and tubes, say copper for the one and brass for the other, would undoubtedly add greatly to the efficiency of these parts. The boilers of the navy are invariably fitted with brass tubes; and but for the first cost of the material, and subsequent outlay for zinc, to prevent galvanic action in the iron plates, it would be a gain to adopt them generally.

We have now considered three of the means of increasing boiler efficiency; but it is clear that anything that can be done with the present boiler is limited by one measure, namely the power of the chimney. Mr. Perkins has shown us that in his boiler, with slow combustion, he can develop in his engine 106 I.H.P., from 600 sq. ft. of heating surface, on a consumption of under 1·7 lb. per I.H.P. per hour, with a working pressure of 350 lbs. per sq. in., and with a weight of boiler and appurtenances—as the writer is informed—only half that of the ordinary form. But it may be doubted whether the tubes forming the furnace, and the rows immediately over the fire, would not very rapidly burn out from the expulsion of the water, under the heat of combustion even of the ordinary 20 to 30 lbs. of fuel burnt, per square foot of grate per hour.

Mr. Perkins has however shown, in the working of his engine and boiler, that cylinders can be worked at 350 lbs. pressure and corresponding temperature, without oil or other lubrication than that of the steam itself; and that boilers can be worked at sea with pure water—themselves making up their own waste—and can be kept absolutely clean and free from injurious deposit. These are important gains to our knowledge, and may no doubt bear results in the future.

The application of forced draught to the furnace has been several times used in marine boilers within the last decade, and promises more than any other method a way to largely increased efficiency, as well as to reduction in weight.

For some fifty years the locomotive boiler has now been in operation, and under the action of the blast pipe has been the most powerful evaporator in existence for its weight. As has been already noted, it does the same work on less than one-third of the weight of the marine boiler. In the case of a vessel of 3000 tons, with engines and boilers of 1500 I.H.P., the introduction of locomotive boilers with forced draught would place at the disposal of the owner 150 tons of cargo space, representing £1500 per annum in addition to the present earnings of such a vessel. The boiler space of such a vessel, arranged on this principle, is shown in Figs. 39 and 40, Plate 71: the stoke-hold S is made air-tight, and two fans FF are used for forcing the air. The arrangement with the ordinary form of boiler is shown in dotted lines for the purpose of comparison; and the shaded portions AA show the spaces saved by adopting the locomotive type.

Mr. Thornycroft has for some years used the locomotive form of boiler for his steam launches, working them under an air pressure —produced by a fan discharging into a closed stoke-hold—of from 1 in. to 6 in. of water, as may be required. The experiments made gave an evaporation of 7·61 lbs. of water, at 212° F., from 1 lb. of coal, with 2 in. of water pressure; and 6·41 lbs. with 6 in. of pressure. These results are low; but it is to be remembered that the heating surface is necessarily small, in order to save weight, and the temperature of the funnel consequently high, ranging from 1073° F. at the 2 in. pressure to 1444° at the 6 in. With the ordinary proportions of locomotive practice the efficiency can be made equal to the best marine boiler, when working under the water pressure usual in locomotives, say from 3 to 4 in., including funnel draught.

It has recently fallen to the lot of the writer to fit three vessels with boilers worked under pressure in closed stoke-holds. The results, even under unfavourable conditions, were very satisfactory. The pressure of air would be represented by under 2 in. of water, and the I.H.P. given out by the engines was 2800, as against 1875 when working by natural draught, or exactly 50 per cent. gain in power developed.

The boilers here alluded to were of the type which, for distinction, may be called the "Navy boiler," Figs. 24 and 25, Plate 65, and they give under ordinary conditions very excellent results. But they have the disadvantage of greater length and weight than the locomotive form, which more than any other, in the writer's opinion, promises to meet the future requirements of the marine engineer.

Two objections to the use of such boilers on board ship have hitherto existed: first, it is supposed they must be deficient in steam room, and therefore very liable to prime; and secondly, there is difficulty in keeping clean, and liability to become salted up.

The first objection is entirely one of construction, and need not exist. The boiler may be made with ample steam room by the addition of a steam dome, or by making the fire-box casing higher than the barrel of the boiler, as shown at D in Fig. 40, Plate 71, so as to be of sufficient capacity, without increasing the weight of water. The second objection can be met, and is now met in most services, by the increased care now taken by all engineers of their boilers, both in working and when in port. The construction of the boiler need not be such as to make it any less accessible than the present marine boiler; and there is no reason why the water need be worse than that used for locomotives on land. As a rule it is much better, when surface condensers are attended to. The principal difficulty is the "human factor;" and it must be admitted that marine engineers are much better educated and more intelligent now than ten years ago, and are becoming more and more so. It is also to be considered that, should their responsibility be increased, they are the more likely to become fitted for it.

Great advantages are to be gained by the introduction of a better form of boiler combined with forced draught, and the locomotive form is that presenting the fewest objections.

In referring to the examples given in Table I., it was shown that the saving in fuel actually effected is equal to that calculated to be due to the use of higher working pressures. This indicates that further progress lies in the same direction; although the future saving may be fractional, and cannot possibly equal past results for the same increments of pressure. Table IV. opposite shows as follows:—

TABLE IV.—QUANTITY OF STEAM AND COAL USED PER I.H.P. PER HOUR FOR VARIOUS WORKING PRESSURES.

(1) *The same Terminal and Back Pressure assumed throughout.*

Total working pressure, lbs. per sq. in. ...	60	75	90	105	120	135	150	165
Number of expansions	4·57	5·72	6·86	8·00	9·15	10·28	11·42	12·00
Steam used per I.H.P. per hour, lbs. ...	21·93	19·13	18·44	17·22	16·4	15·65	15·0	14·53
Net coal per I.H.P. per hour, lbs.	1·8	1·58	1·52	1·43	1·36	1·30	1·25	1·224
Ratio of net coal to that at 105 lbs. taken as unity	1·26	1·104	1·061	1·000	0·95	0·91	0·875	0·8545
Do. do. 60 lbs. do.	1·000	0·8775	0·842	0·794	0·755	0·7225	0·695	0·6786

(2) *Six Expansions, and the same Back Pressure assumed throughout.*

Total working pressure, lbs. per sq. in. ...	60	75	90	105	120	135	150	165
Steam used per I.H.P. per hour, lbs. ...	19·09	18·88	18·45	18·1	17·81	17·6	17·42	17·2
Net coal per I.H.P. per hour, lbs.	1·569	1·556	1·528	1·502	1·483	1·469	1·458	1·442
Ratio of net coal to that at 105 lbs. taken as unity	1·043	1·035	1·016	1·000	0·988	0·977	0·97	0·959
Do. do. 60 lbs. do.	1·000	0·9925	0·964	0·96	0·945	0·935	0·929	0·918

(3) *Eight Expansions, and the same Back Pressure assumed throughout.*

Total working pressure, lbs. per sq. in. ...	60	75	90	105	120	135	150	165
Steam used per I.H.P. per hour, lbs. ...	18·8	18·1	17·64	17·21	17	16·65	16·5	16·39
Net coal per I.H.P. per hour, lbs.	1·544	1·491	1·459	1·429	1·415	1·388	1·38	1·373
Ratio of net coal to that at 105 lbs. taken as unity	1·053	1·043	1·021	1·000	0·991	0·972	0·966	0·962
Do. do 60 lbs. do.	1·000	0·966	0·945	0·925	0·917	0·897	0·894	0·89

1st. The quantity of steam and coal used at pressures varying from four to eleven atmospheres, assuming the ratio of expansion to be varied so as to produce the same terminal and back pressure;

2nd. The same, assuming *six* expansions and the same back pressure;

3rd. The same, assuming *eight* expansions and the same back pressure.

The total working pressure of to-day may be accepted as 105 lbs., or equal to seven atmospheres. If it were boldly accepted that eleven atmospheres, or 165 lbs., should be the standard working pressure, the best result, with twelve expansions, would be a saving in fuel of 14·55 per cent., provided no counteracting influence came into play. Of course, there are forces which war against the attainment of this advantage to its full extent, viz., the greater condensation in the cylinders and loss in the receiver or passages.

In regard to condensation in the cylinders, it may be questioned whether by steam-jacketing the high-pressure cylinder, correctly proportioning the steam passages, and giving a due amount of compression in both cylinders, this may not be reduced far below the generally received notion; and the loss in the receiver and passages may be considerably reduced in its effect by a more carefully chosen cylinder ratio. The ratio usually adopted, between 3·5 and 4 to 1, whether the pressure be 70 or 90 lbs., may well be questioned, in view of the results shown in the case of Nos. 6, 15, and 17 in Table I. (p. 452). There, with a cylinder ratio of 2·95 to 1, the economic performance is very good, and equal to any with the higher ratio; and it may be added that these three cases quoted are amongst the most reliable and trustworthy of the list.

A lower cylinder ratio has another advantage of considerable value, viz., that the working pressure can be much reduced as the boilers get older, while by giving a greater amount of steam the power may be maintained—at an extra cost of steam, of course, but not so great a cost as with higher ratios. This fact was mentioned by Mr. McFarlane Gray in the discussion on Sir Frederick Bramwell's paper in 1872.

The starting has usually fixed the cut-off in the high-pressure cylinder at about 0·6 of the stroke, and the ratio of expansion has

decided the ratio of cylinders. The use of separate starting valves in both cylinders obviates that necessity. The difficulties in the way of taking advantage of the higher economic properties of pressures above those hitherto used on board ship, are, it is submitted, not insuperable, and it would be to the interest of all that they should be firmly and determinedly met.

The quantity of steam used in the compound receiver engine and Woolf engine, respectively, are stated by Mr. D. K. Clark in his Manual of Rules, Tables, and Data to be—

Receiver Engine	18 to 20 lbs. per I.H.P. per hour.
Woolf Engine	20 to 21 lbs. per I.H.P. per hour.

It is a remarkable coincidence that the long-voyage results, given in Table I., exactly confirm Mr. Clark's figures. It may therefore be accepted as an average result that the Woolf engine, as usually arranged, will use 10 per cent. more steam than the receiver engine for the same power. For the three-cylinder receiver type the data are insufficient to form a definite opinion upon; but so far the general working of the *Arizona* is stated to be as good, economically, as in any of the two-cylinder receiver class.

It is only right to mention here that the results referred to are very seriously affected by the condition of the valves and gear at the time; and still more by the setting of the valves, and the relations of the admission, port-opening, release, and compression, to the movements of the piston. The efficiency of an engine may be reduced enormously by carelessness in this respect, and when efficiency is of such vital importance, these matters of detail cannot be too strongly urged upon steam-ship owners. It is not too much to say that nine-tenths of the engineers in charge of engines know nothing of the condition of their valves, and it is not till some serious waste or mishap occurs that they are thought of.*

* The subject of valve motions was so fully discussed at the Barrow meeting (Proceedings 1880, pp. 418–454) that it is unnecessary to go over the ground again. Those members who are interested may see a model and photographs exhibiting the application of that modification of the Hackworth motion adopted by the writer. It is now at work in thirty-two sets of engines, and is being fitted to as many more by his own and other firms. It is working very satisfactorily in every instance.

The Surface Condenser remains as it was ten years ago, with scarcely a detail altered. In most engines it remains a portion of the framing, and as such adds greatly to the weight of the engine. It is a question seriously worth consideration whether or no the area of tube-surface can be reduced. The practice at present is to make the condensing surface one-half the heating surface as a minimum, that is, equal to about 2 sq. ft. per I.H.P. In practice, the writer has found 1·4 sq. ft. per I.H.P. to maintain a steady vacuum of $27\frac{1}{2}$ in. The only experiments on this subject of a practical and accurate character are those conducted by Mr. B. G. Nichol, of Newcastle, an account of which appeared in "Engineering" of 10th December, 1875. It was found that, when the water flowed through horizontal brass tubes with a velocity of 78 ft. per minute, 1 sq. ft. was quite sufficient to transfer 533 units of heat per hour from the vapour of the condenser to the water, for each degree Fahr. of effective difference of temperature. Now in general we only have 200 units transferred for each degree of effective difference; so that, even with water flowing through at the slow velocity named, there is a large margin for the dirt frequently found in the tubes of condensers. Then again, an engine using 22 lbs. of steam per I.H.P. per hour must require more surface than one using 16 lbs.; and if 2 sq. ft. per I.H.P. be necessary for 22 lbs., while, by increasing the initial pressure, the quantity of steam can be reduced to 16 lbs., we should only require 1·45 sq. ft. per I.H.P. to give the same vacuum, if the condensing water remained the same.

The method generally in use, of passing the water through the inside of the tubes, is much more efficacious than passing the exhaust through them, as is sometimes done in H.M. Navy. The circulation is never so perfect in the latter case, and much more water is carried. The ordinary plan gives more control over the quantity, and also better circulation of the water.

The air and circulating pumps, for engines of 1500 I.H.P. and under, are as a rule worked entirely by levers attached to the low-pressure connecting-rod cross-head. They thus help to balance the piston and rods of that cylinder. The circulating pump is made single or double acting; the single-acting has the advantage of adding to the balancing of the weights, and offers no obstruction to the flow of

water; the double-acting has the effect of checking the column at each stroke, and is not so easy in working.

The Gwynne centrifugal pump is extensively used for circulating and bilge purposes, and is a very valuable auxiliary to the main engine pumps.

The extended use of steel offers great advantages in the reducing of weights, and especially in the form of hollow shafts, such as are now being manufactured by Sir Joseph Whitworth and Co. On this system, in a 10-inch shaft, a hole is run 4 in. in diameter, reducing its weight 16 per cent., while its strength is only reduced 2·56 per cent.; or, if the hole were increased to 5 in., the weight would be reduced 25 per cent. and the strength only 4·25 per cent.; and it is a question whether the weight could not be further reduced by giving a lower nominal margin of safety, which it would seem might be done on account of the greater elasticity of form, as well as elasticity and homogeneity of material. The surface presented by a steel shaft to the bearings is also—it is not too much to say—almost infinitely more perfect than by the forged iron shaft, with its reeds, open texture, and iron cinder, from which marine engineers suffer so much. The friction must therefore be greatly reduced.

The writer has just completed six pairs of engines for three twin-screw ships, having steel shafts of 10 inches diameter, and has in each case run the engines at 120 revolutions per minute, while indicating 1380 H.P. from each pair, for ten to fifteen hours without stopping; and in no case has a single bearing or crank-pin warmed or had water applied, the surfaces on examination being perfect.

In these engines all working bolts, pins, and rods, except the piston-rods and connecting-rods, are of steel, all rods in tension being loaded to 8000 lbs. per sq. in. The boilers are of the Navy type, made throughout of Siemens-Martin steel plates, riveted with steel rivets, all holes drilled. The furnaces are welded and flanged; the tubes are of brass. In comparison with an ordinary merchant steamer's iron boilers of the double-ended type, their weight, including water and all appurtenances, and their other particulars, are as follows:—

	Double-ended Type.	Navy Type.
Weight, tons	135	146
I.H.P.	1400	2760
Draught	Natural	Forced.

The use of steel castings is becoming considerable: they give great strength, but unfortunately the still persistent presence of blow-holes prevents their strength, and their wearing to a polished surface, being relied on to the extent that could be wished.

For our large steamers steel-built crank-shafts must come more and more into use. The constant failure of iron cranks, even when built up, is too serious a question for the shipowner to let alone long. It is important to note Mr. Holt's remarks on his return to the old-fashioned mill-engine form of crank, Figs. 33 and 34, Plate 70. The single bearing of great length on the end of a long length of screw-shafting—the crank-pin with small surface velocity—the simple crank, made, as it can now be made, to be practically solid with the shaft—are all great steps in the way of simplicity; provided only shipowners care to adopt the single engine, which, even if ten per cent. more costly in fuel, has much to commend it.

The cast-steel propeller blades, introduced by Messrs. Vickers, are being more largely used; the reduction in thickness enables them to be much more easily driven.

The screw propeller is still to a great extent an unsolved problem. We have no definite rule by which we can fix the most important factor of the whole, namely the diameter. Mr. Froude has pointed out that by reducing the diameter, and thus the peripheral friction, we can increase the efficiency; and this is confirmed by the cases of the *Iris*' screw reduced by 2 ft. 3 in., and the *Arizona's* reduced by 2 ft. This must of course be qualified by other considerations. The ship has by her form a definite resistance, and a certain speed is required; if the propeller be made too small in diameter, the ship will not be driven at the required speed, except at serious loss in other directions.

This question is too large and complicated to be dealt with here, and should, in the first instance, be made the subject of careful and extended experiment, on which a separate paper should be written. The writer's object is to point out the important bearing the question has upon the marine engine. We have shown the importance of the reduction of weight to the shipowner; the smaller the propeller, the smaller the engine needs to be to drive it, and therefore the less the weight to be carried; but to produce the same result in driving the ship, the propeller will need to be turned faster; and the faster it

can be turned, consistent with efficiency and small wear and tear, the better. That in our ordinary practice we are a long way within our powers, in this latter respect, is proved by the engines of torpedo vessels developing 470 I.H.P., at 443 rev. and 886 ft. piston speed per minute; the *Iris* developing 3857 I.H.P., at 99 rev. and 582 ft. of a 75-in. piston per minute; and the recently constructed engines, before alluded to, giving out 1400 I.H.P., at 124 rev. and 724 ft. per minute of a 60-in. piston. To do this however the working parts must be carefully balanced—a matter very much neglected, but neglect of which leads to great wear and tear in shafts, crank-pins, &c. Such effects, not being considered sufficiently in the first instance, are urged against the adoption of higher velocities, not specially in the piston, but, what is far more important, in the speed of revolution; which, as experience is showing us, may be vastly increased to the advantage of all, and specially of the shipowner, whose interests it is the first interest of marine engineers to promote.

To sum up the whole. Progress has been made during the past nine years, and in the following particulars.

1. The Power of the Engines made and making shows a great increase.

2. Speeds previously unattainable are now seen to be possible in vessels of all the various classes.

3. The Consumption of Fuel is reduced by 13·38 per cent. on the average; and numbers of vessels are now working on much less coal than that average, while the quality of the coal is in nearly all cases very inferior, so that it is not unfair to take credit for 20 per cent. reduction.

4. The Working Pressures of Steam are much increased on the average, and are still increasing; many steamers now being built for 120 lbs. per sq. in., while 90 lbs. is the standard pressure now required.

As increased pressure means increased efficiency, there does not appear any reason why the standard of 150 lbs. should not be sought as that of the future; combined with the adoption of the locomotive

type of boiler and forced draught. Higher speeds of revolution appear to be desirable, with a view to very great reductions in weight of machinery carried. This implies careful balancing and careful adjustment of all working parts, as well as of the steam, to the work to be done.

The more general introduction of steel in all its varieties is enabling the marine engineer to adopt means tending throughout to lighten working parts, and to increase velocities, in a way he dared not attempt nine years ago.

In conclusion the writer begs to submit this paper to the Institution as a very imperfect *résumé* of the progress and development of the marine engine, and only as a sequel to that of his distinguished predecessor. His time has not permitted him to go fully into the many questions arising out of the subject, and he asks that the paper may be received only as a basis of discussion by the Institution, many members of which are much better able to deal with the matter than he feels himself to be.

The writer desires to tender his warmest thanks and acknowledgments to the numerous shipowners, manufacturing engineers, marine superintendents, and others, who have so freely supplied him with valuable information for this paper, some at considerable expense and trouble. He has also pleasure in acknowledging the careful assistance rendered by Mr. A. Blechynden, M.I.M.E., in the preparation of the details and calculations of the paper.

Discussion on The Marine Engine.

Mr. Marshall wished to make one remark with reference to the consumption of coal, as shown in the last column but two in Table I. (p. 452). In the steamer No. 39 the consumption in 24 hours was put down at 137 tons; but with better qualities of coal, as he was informed in a letter received that morning from the superintending engineer, 110 tons would be more correct. That confirmed the remark he had made in the paper, namely that 13·37 per cent. saving in fuel, during the last nine years, did not fairly represent the money value, or the real progress, in the economy of fuel. In the case mentioned, there was a difference of 27 tons out of 137 tons, due to the quality of coal; and no doubt the same applied to many others of the cases in Table I.; so that he thought it was perfectly fair to say the saving of fuel had been 20 per cent. during the last nine years.

Mr. A. C. Kirk thought that they were much indebted to Mr. Marshall for bringing before them a fair *résumé* of the state of marine engineering at the present time. He had not been able to mark any great step taken within the last nine years; but that was by no means his fault, because the fact was there had been no great step whatever taken during that period. Engineers had gone on gradually increasing the working pressure; and he ventured to think that with the present compound engines it had been increased quite as far as there was any advantage in doing so. The pressures were such that each of the separate cylinders was now brought nearly to the state of the single cylinder in the old engine, before it was compounded. If full advantage were taken of the present pressure of steam—say 90 lbs. or 100 lbs. per sq. in.—and a high grade of expansion were used in a two-cylinder compound engine, it would be found that in one or perhaps in both of the cylinders they were doing too much expansion (three times in any one cylinder being as much as ought to be used); or, what was still worse, much of the expansion was got by an inordinate drop of pressure in the receiver.

In either case the range of temperature in each cylinder was getting too great. About eight years ago, in a ship fitted with Mr. Rowan's boilers, carrying a pressure of 150 lbs., it had fallen to his lot to design cylinders with triple expansion; and the results, so far as the engines were concerned, had proved so far satisfactory that at the present moment his own firm were doing the same thing with 125 lbs. pressure in ordinary boilers. He could not at present say anything as to the success of this attempt, but the previous case had been very successful.

As to the consumption of coal, Mr. Marshall's figures pretty fairly represented the average saving in consumption during the last nine years: certainly the consumption was not more than was shown in Table I. (p. 452). He was not prepared to credit anything to the use of inferior coal, because he found that the long-voyage ocean steamers, in which the consumption of coal was best tested, always used good Welsh coal. He should not himself put the improvement at more than a reduction from the previous consumption of 2 lbs. of coal per indicated horse power per hour to a present consumption of 1·8 lb.; and considering that the pressure had been increased from 60 up to 90 lbs., he did not think the economy in coal had kept pace with the increase in the weight and cost of the engines.

The Woolf engine had been spoken of in the paper (p. 453) in a way that might be slightly confusing. When Messrs. Randolph Elder & Co. introduced their first compound engines, those had been what were properly called Woolf engines. The expansion was first carried on in the high-pressure cylinder as far as was desirable, and then in the return stroke the expansion was continued simultaneously in both the high-pressure and the low-pressure cylinder down to the point of suppression. In that engine the temperature of the high-pressure cylinder varied through the full range that would occur in an old-fashioned single engine, except the drop in temperature from that of suppression to that of the condenser. While this type was in use, the compound marine engine made but little progress. The results were no doubt better than in the ordinary engine, but they were not what they should be. He believed it was due to the President, Mr. Cowper, that the receiver type of engine had been

introduced, and brought prominently before the public.* By that means the range of temperature in the high-pressure cylinder was materially reduced. He wished to draw attention to that point, because Mr. Marshall's idea of a Woolf engine appeared to be rather that of an engine in which the two pistons necessarily moved simultaneously in the same direction, or, as in Mr. Elder's engines, in opposite directions. But the engines shown in Plate 58 were not Woolf engines in the proper sense of the word. They were really two receiver engines, with the two pistons working simultaneously in the same direction. If they were made real Woolf engines, there would in that case be such an enormous clearance between the cylinders that there would be a serious loss of effect.

The paper stated (p. 453) that a tandem engine might be multiplied indefinitely in a ship. But any other kind of engine might also be multiplied indefinitely: he failed to see that that was an advantage belonging to the tandem engine alone. He wished also to correct one slight error in the paper: it was not Mr. David Rowan, but Mr. John M. Rowan, who had introduced the type of three-cylinder engine mentioned on page 453 and shown in Plate 59.

One important point to which the paper had referred was the question of reducing the weight of engines. The engines of the *Nelson*, shown in Plate 66, had been designed by himself for the Admiralty, and the weight had been a matter of vast importance; but he had never had an opportunity of introducing the same design in the Merchant Service, and he should think twice before he seriously propounded the idea to a shipowner. It was a very expensive form of engine. True it saved weight; but it was not in every ship that the saving of weight was of value. There was a very large class of ships of which the freight-earning power depended upon how much bulk they could contain in measurement,

* The following note has been supplied by the President. "About 1838 a small steamboat, the *Era*, had a high and a low-pressure cylinder, with a pipe connecting them, and cranks at right angles; in 1857 a pair of 60 horse-power engines with high and low-pressure cylinders had a steam-jacketed receiver added to them by E. A. Cowper; in 1862 he improved the receiver, and in 1864 he read a paper on Compound Engines at the Institution of Naval Architects."

not how much dead weight they could carry; and even the owners of ships in which the freight depended simply upon dead weight would think twice before paying anything extra for the engines. He had always found light engines expensive. Their costly workmanship and large amount of high-class material cost more than less costly workmanship and a larger quantity of lower-class material. There was another engine, shown in Plate 67, with wrought-iron frames and diagonals, but stiffened fore and aft instead of athwartship; this however was for a torpedo boat, in which the transverse strains were taken by the hull.

He might be permitted to point out that the three-cylinder compound engine was rather older than Mr. Marshall seemed to be aware. His own impression was that he had first seen it in France; at all events the first examples of that particular type, Plate 60, but fitted with piston-valves, had been made for the *Iberia* and the *Liguria* about 1875. But the late Mr. Elder had made for H.M.S. *Constance* a three-cylinder compound Woolf engine about the year 1858 or 1859. There were two sorts of three-cylinder compound engines, as there were of two-cylinder engines; but Mr. Elder's was a Woolf engine, having continuous expansion in the high-pressure cylinder.

He would now make a few remarks on the subject of boilers. Unquestionably the type of marine boiler was practically fixed for the present. It was a very good boiler; and with the restrictions due to the somewhat paternal way in which marine boilers were treated, he thought it would be some time before that type was departed from. It certainly would not be seriously departed from unless by some one who had great patience, and was prepared to spend a great deal of money. The locomotive type of boiler was however worthy of the attention that Mr. Marshall had given to it. It might seem singular, but no shipbuilder would be allowed to take a locomotive engine from a railway station and put it on board a ship to work at the same pressure. It was considered safe enough on land among thousands of people, but it was thought it would not do at sea.

Whether a forced blast was to become a feature of the future boiler for ships going long voyages—to Australia for example—he

was not prepared to say; but there was a class of steamers going short voyages, of very high speed and limited draught of water, where weight must be kept down; and there the forced blast continuously applied was not only admissible, but, he ventured to say, was the only rational solution of the problem.

As to the remark, p. 474, about the two different classes of condensers, one condensing inside the tubes and the other outside, in his opinion it was simply a question of the circulation of the water. The one condenser was as efficient as the other, if the circulation were made alike. Where the water was inside the tubes, it happened to be perfectly easy to secure good circulation; but the other condenser could be made equally good by putting in two or three diaphragms or baffle-plates to direct the water across the tubes.

Attention had been drawn (p. 475) to steel castings, in regard to their saving of weight. In the present engines that his own firm was building for the Admiralty, and indeed in a previous set, cast-steel pistons had been used. In order to test them, they were bolted together in pairs by the centre, with an india-rubber joint round the circumference, but no bolts to connect them there; and water was pumped into the space between them. They were thus tested at 90 lbs. per sq. in., and at that pressure there was no appreciable deflection whatever. They gave no trouble with blow-holes in the castings; there were one or two blow-holes, but they were quite insignificant. He had also used other castings in steel—large eccentrics and so on. The question was one well worthy the attention of marine engineers. Levers, for instance, might be made of cast steel, saving in many cases all the trouble of using plant for forging and machining them, where it was not necessary to give any high finish.

He thought there was some confusion in regard to one statement in the paper, p. 476: "the smaller the propeller, the smaller the engine needs to be to drive it, and therefore the less the weight to be carried." But in the *Iris* the propeller was reduced, keeping the same engine, and a higher speed was obtained with the smaller propeller than with the larger one. He failed to see that there was any connection between the size of the propeller and the size of

the engine. A small propeller had naturally a greater pitch given to it, when intended to be driven at the same number of revolutions per minute and to produce the same speed of vessel as a larger propeller; but the reduction in its diameter was made with a view to reduce its friction in the water, and need not involve reducing the size of the engine.

Mr. George Crow had had many years' experience in building single-crank tandem engines of the class shown in Plates 55 and 56. The paper alluded to the difficulty of handling these engines in starting and stopping (p. 453). He himself generally went to sea with the engines during their trial trips; in all cases he had seen his engines tried, and he could state that there was no difficulty in starting. There had been some difficulty previous to the introduction of good steam reversing gear; but now the man in charge, if a skilful engineer, could work the engines a half stroke or any portion of a revolution, and never allow them to get on the centre, thus working them like a pumping engine. It was true there was what was called a steam turning engine, for the purpose of overhauling the engines in port, and for warming through before putting the main engines under way; but he did not think he had ever seen it used for the purpose of pulling the main engines off the centre, since the application of steam reversing gear.

The paper stated, p. 473, that "the Woolf engine, as usually arranged, will use 10 per cent. more steam than the receiver engine for the same power." He was at a loss to understand how that could be. In the Woolf engine the steam exhausted direct from the high-pressure down to the low-pressure cylinder, with no chamber between the two; consequently there was less surface for condensation, both externally and internally. He therefore thought it would be difficult for any one to prove that two cylinders side by side, with a receiver between, could be more economical in fuel. If true, it could not result from the arrangement of the engine, but from some other cause. The last engine he had made of the class referred to was for the screw steamer *Vega*, sailing to Calcutta for Messrs. Rathbone, Liverpool, carrying a dead-weight cargo of fully 3,500

tons, and of 1,600 I.H.P.; and she averaged for the entire run $11\frac{1}{2}$ knots per hour, consuming $1\frac{3}{4}$ lb. of coal per I.H.P. per hour.

Mr. John Rogerson was very glad Mr. Marshall had brought forward his paper, as he had taken the opportunity of consulting that gentleman, for the last twenty years and more, on the building of engines and boilers. He thought it was only fair to refer to one point mentioned in the paper in relation to the Perkins boiler, p. 458: "It must be admitted that the tubulous system has not been a success." Now the Perkins system had as yet been tried to a very limited extent only. In the case of the *Emily*, Mr. Perkins stated that it had been a success; and the *Anthracite*, built upon the Tyne —a small boat 60 ft. long—had gone to London and then across to America and back, with a very small consumption of fuel; and he believed she had given every satisfaction to the builders. But he wished particularly to refer to the *Loftus Perkins*, which had been built and run by the Tyne General Ferry Co., as a passenger steamer on the Tyne. The safety-valves were loaded to 450 lbs. per sq. in., and the boiler tested to 2000 lbs. per sq. in. The engines had three cylinders, one high-pressure 10 in. diameter, one medium 14 in., and one low-pressure 28 in.; the length of stroke was 18 in., and the power 125 I.H.P. The fuel was gas coke; and the consumption under trial in a day's work of thirteen hours was 25 cwt., or 1·72 lb. per I.H.P. per hour. The vessel had run with passengers ninety-one days, making in all 5,582 miles, in addition to a great number of trial trips. After this period, during six months of which a Board of Trade certificate for passengers had been held, the boiler tubes were drilled for the surveyors to examine, and proved perfectly clean and free from scale. The consumption of second-class steam coals in other boats doing the same work, with ordinary oscillating engines, was 3·09 lbs. per I.H.P. per hour, or 45 cwt. per day, costing 13*s.* 6*d.*, as against 6*s.* 3*d.* for the *Loftus Perkins*: showing a saving in favour of the latter of 44 per cent. in weight of fuel, and 54 per cent. in cost of fuel. There was a defect in the engines, but it was a mechanical defect, arising from the boat being very limited in size, and did not affect the system. He believed a boat on this system

was now running between Greenock and Belfast, and was proving that the system was one of the most economical in regard to the consumption of fuel.

In reference to the use of steel castings, the complaint made as to blow-holes might be sometimes well founded; but it was not so in all cases. Steel castings, such as Attwood's castings, as now made in the district of Newcastle, were perfectly solid, and no blow-holes could be seen in them.

Sir F. J. Bramwell said there was one question that lay at the root of the matter of fuel consumption, both as stated in the paper and as presented by himself at the meeting of the Institution in Liverpool in 1872; namely, how was the gross indicated horse-power ascertained? in other words, what was the divisor used for the coal consumed? He thought this really ought to be known in each case; because, if the gross horse-power indicated, say upon a trial trip, were used for the divisor of the coal consumed during a voyage, results might be arrived at which were not accurate. The last speaker had alluded to some of Mr. Perkins's boats. He himself might perhaps be permitted to mention that in the case of the recent trial of the *Anthracite* (after her voyage to and from America) conducted by Mr. W. E. Rich and himself, and in the presence of Mr. Thornycroft, the method pursued to obtain a trustworthy result was as follows. Indicator diagrams were taken every half hour until they ceased to put coal upon the fire; then they were taken every quarter of an hour; and then, when the engines fell off from their normal speed, they were taken every five minutes until the engines came to a stand. It might interest the meeting to know that Mr. Thornycroft, who at this time went into the boiler room to see how much fire remained on the bars, found the fire-box in complete darkness, and had to take a light to look for what was left of the fuel; this was found to be only a few cinders, so cold that they could be carried in the hand. The engines worked until the effective boiler pressure had fallen to zero, at which time they came to a dead stand, having just before been making from 28 to 30 revolutions per minute. The time of running was 12 hours and 10 minutes. Every

pound of coal used in getting up steam and consumed during the run was debited to the engine; and the total foot-pounds exerted in the 12 hours being known, a proper divisor and dividend were obtained. The resulting quotient was 1·79 lb. per I.H.P. per hour, including the getting up of steam; while, omitting the getting up of steam, and assuming the fire to have been in the same state at the end of 7 hours' work out of the 12 as it was at the beginning, the consumption in that time was 1·66 lb. per I.H.P. per hour.

He wished to refer to one other matter in that boat, namely the condenser, which he considered to be of an extremely good construction. The arrangement was that of vertical close-topped tubes, having open-ended tubes within them. The close-topped tubes terminated at their bottom ends in one tube-plate, and the open-ended tubes in another. The condensing water went up through the open-ended tubes and then came down through the annular space between the two tubes, and all difficulties of expansion were got over. A steady vacuum was maintained of $28\frac{3}{4}$ to 29 inches of mercury the whole time.

There was one other point to be referred to, namely that of the forced draught now being adopted. He had previously stated to the Institution that he had seen used in America in 1853, in paddle steamers burning anthracite coal, a system of forced draught, with the stoke-hold under pressure. He did not think there could be any practical objection to it; on the contrary, he should think the men in the stoke-hold would be glad of anything that would ensure to them sufficient ventilation.

Mr. W. Parker said he agreed generally with what Mr. Marshall had laid before them in his valuable paper, so far as the reduction of consumption was concerned. As regarded the reduction of 50 per cent. referred to by Mr. Marshall, and also mentioned in the discussion upon Sir F. Bramwell's paper in 1872 as having been obtained in the preceding nine years, he thought it would be freely acknowledged to have been due to the general adoption of the surface condenser and the compound engine. A similar reduction could not be expected in the following nine years; still, as Mr.

Marshall had shown, a reduction had steadily gone on. The paper stated the reduction at 13·37 per cent., and this on the assumption that the pressure had reached only 77 lbs. This was no doubt the average pressure for the several vessels referred to in Mr. Marshall's paper; but for boilers now being built he ventured to say that 77 lbs. was nothing like the average pressure: 90 lbs. would be very much nearer the mark. In estimating the reduction of fuel consumption obtained during the last nine years, it was not only the average pressure in a number of steamers actually running which should be taken, but also the maximum pressure; and every one would admit that 100 lbs. was now becoming a common pressure. The introduction of steel and of corrugated furnaces had led to an increase of pressure equal to at least 33 per cent.: this had taken place within the last $2\frac{1}{2}$ years, and he ventured to think that if, instead of the average pressure, Mr. Marshall had taken into consideration the maximum pressure given by those improvements, the saving of fuel shown would have been fully 15 per cent., instead of 13·37 per cent., as compared with 1872. Instead of considering that they had got to the end of their tether, he thought they could still go somewhat further in this direction. It had been suggested at some of their meetings that boiler shells might be constructed in solid rings. If that could be done—and eminent steel-makers said it was quite possible—there would be another increase of pressure of 25 per cent.; because the strength of a boiler shell was of course governed by the strength of the seam, and it was impossible to obtain, even by double-riveting, above 75 per cent. of the strength of the solid plate; hence if the plate were solid, there could be at least another 25 per cent. increase of pressure.

He rose however chiefly in consequence of a remark in the paper about the restrictions imposed by Lloyd's Register, and by the Board of Trade. He hardly expected to hear that from Mr. Marshall, who he thought had given them credit at Lloyd's for not trying to obstruct, but rather striving to promote progress. There were certain differences between the rules of Lloyd's Register and the rules of the Board of Trade, which he might explain, as they had been commented upon by several engineers in the district. The strength

required in a cylindrical boiler shell had been laid down by the Board of Trade to be six times the working pressure. Thus the shell of a boiler to work at 100 lbs. should not burst at less than than 600 lbs. At the present time engineers were testing the material used in these shells, so that such a high factor as 6 was not required to cover any inequality of material. Again, they had tested so many seams that they knew from calculation the strength of the seam as compared with the solid plate; so that the factor of safety of 6 was not required to cover any defect in the construction. The only other element appeared to him to be corrosion. Now corrosion, every one would admit, was a constant quantity, whether in a thick or a thin plate; and if a factor of 6 was found to be quite sufficient for thin plates, he submitted that for thick plates it was altogether too high. The loss of $\frac{1}{8}$-in. on a $\frac{3}{8}$-in. shell plate would reduce the strength of the structure one-third, whilst the same amount of corrosion on a 1-in. plate would reduce it only one-eighth. Lloyd's rules took cognisance of this difference, which the rules of the Board of Trade did not provide for.

Mr. Marshall had referred to the large steamers now being constructed. Just now they were on the eve of a very great experiment. The *Servia*, the *City of Rome*, and the *Alaska* would in a few months be racing across the Atlantic; the powers to be exerted by them were unprecedented; nothing of the kind had been witnessed in the mercantile marine; and all were looking forward with great interest to the results that would be obtained by these huge vessels. It would hardly be right to criticise those vessels before they began to run; but he nevertheless believed that if those vessels, which were going to transmit such enormous power through a single screw, had been made with two screws, a better result might be obtained.

Mr. W. E. Rich said that the author's valuable paper showed an immense amount of labour in collecting and tabulating the statistics brought forward; and he had also given them the benefit of his large experience in discussing the present condition and probable future development of the marine engine. With regard

to Table I. (p. 452) he ventured, with Sir Frederick Bramwell, to doubt the extreme figures that were there given. They would all alike rejoice when they had indubitable evidence of a consumption of only 1·5 lb. of coal per I.H.P. per hour, as recorded in the Table, either in marine or in land engines; but he feared that result was not nearly attained yet. He had of late years tried many experiments with land engines on the compound principle, having every provision about them to ensure economic working; and he must say he had failed to obtain a lower consumption than 2 lbs. of coal per I.H.P. per hour. This led him to suspect that only the best engines ten years ago worked with 2·1 lbs., and only the best now with 1·8 lb. He should like to know, as well as the coal, the weight of steam used per I.H.P.; then they would be able to determine how much of the improved economy of late years was due to the modern compound engine, and how much to the higher pressure in the boiler. They could then determine also the relative merits of the locomotive and other types of boiler, so far as economy was concerned. Mechanical questions must affect the construction of a boiler, as well as those of economy; but he believed the locomotive type to be one of the best for obtaining a large weight of steam per pound of coal burnt in the fire-box. They had seen what had been done by portable engines, which had boilers of the locomotive type.

With regard to the question of mechanical efficiency, what was wanted was not only to indicate great power in the engines, but to get as much of that power as possible upon the screw-propeller; and he was afraid they were still considerably in the dark as to how much of the power developed in the engines got through to the screw-propeller. The late Mr. Froude's marine dynamometer had, he believed, only been tried once. Having attended that trial at Devonport, he believed it would become a most valuable instrument when there had been a little more experience in its use. Mr. Edward Froude had told him, a few weeks ago, that he did not consider the statistics of the first trial satisfactory enough to be placed before the world, but he hoped to make other trials with the instrument soon. During the one trial already made, the power diagram showed

a succession of waves of delicately refined outline, one wave being described for each revolution. The shape of the wave varied very much with the ratio of expansion; and he believed that such wave outlines would tell a great deal as to the effects of vibration &c. upon the screw-propeller shaft, and as to economy in the propulsion of vessels.

The President, in his opening address, in speaking of some of the modern improvements in marine engineering, had referred to Mr. David Joy's valve-gear. Such types of gear were certainly very interesting. He learnt that Mr. Marshall had fitted thirty vessels with his own gear, which were all doing well. It was certainly a step in advance in marine engineering to see such forms of valve-gear coming to the front; and one great advantage derivable from them was the getting of all the expansion desired, with a single slide-valve.

Another point of importance in large engines was the introduction of piston-valves, which appeared to be very much in vogue among the Clyde shipbuilders; if experience gave good results with those valves, he thought they would come to be much more used than they now were. The high-pressure steam-valves in Mr. Perkins' experimental steamer *Anthracite* were peculiar, being cast-iron mitre valves, unbalanced, and working on cast-iron seats, with a small lift and feather guides. They worked extremely well, and after going to America and back the engines seemed to give excellent results with them. One could not hear them work, when going at 110 revolutions per minute.

With reference to surface condensers, he agreed with Mr. Marshall that even now the surface might be very much reduced. It was only natural to expect that, in proportion as engines used steam more economically, condensing surface might be reduced; and even more than in direct proportion, because the steam would leave the cylinders at a lower temperature.

Mr. B. G. Nichol thought the present discussion would serve as a landmark in the history of the marine engine. So far as he had been able to judge, there appeared to be three distinct views before

the meeting. The first was enunciated in the letter written by Mr. Holt, namely that the compound engine would be abandoned, and a return be made either to a simple pair of expansive engines or to a single engine. Then there was a second view, which he might call the "finality" view, enunciated in the remarks of Mr. Kirk: and no doubt the present compound engine was a very perfect machine. The third view was that enunciated in the paper, which boldly launched out into speculation, and suggested the direction of future improvement.

With regard to Mr. Holt's view, he thought there was much to be said in its favour. In the first place the engine was reduced to its simplest form; and a further point might be mentioned in its favour, namely the results obtained in America with long-stroke engines, where the diameter was very small in proportion to the stroke, and consequently the clearance spaces, and the amount of surface exposed at the ends of the stroke to the condenser, were very small in relation to the steam admission. But the same argument might also be used in favour of the present compound engines—that if the length of stroke were increased there was no question but that a still higher amount of efficiency would be attained. As to the present engine, the results in Table I. (p. 452) were most excellent. From the averages of the figures quoted, he made out that there was an efficiency due to the boiler of nearly 75 per cent.; whence, assuming the full value of 1 lb. of coal to be $13\frac{1}{2}$ lbs. of water evaporated from 212° Fahr. at atmospheric pressure, the boiler efficiency would be 10·06 lbs. of water so evaporated per lb. of coal; or 8·75 lbs. evaporated under the mean boiler pressure as given, of 77·4 lbs. per sq. in. above atmosphere, with feed water entering at 100°. Then 8·75 multiplied by the mean consumption of 1·828 lb. of coal gave nearly 16 lbs. weight of steam per I.H.P. per hour, which was certainly a very excellent result; and he doubted very much whether an engine could be made to use steam more economically than that. He agreed with Mr. Marshall however that the boiler afforded ample room for improvement. He thought the direction indicated—working under a pressure of air—seemed to point to an unmixed good, enabling the weight both of the boiler

and of the water carried to be reduced greatly. Seeing that Mr. Marshall had obtained with forced draught nearly 50 per cent. more power than with the natural draught, he thought it was certainly worth a trial on a large scale in the mercantile marine.

There was one more point to which he should like to call attention, as to the coal used per I.H.P. There ought to be some standard to work to, which should be taken as unity, and should be the result obtained under the best conditions; and then what was obtained in actual working would be some percentage of that standard. He had been investigating for some time the coal used by two or three lines of steamers, and he had found that when the coal was supplied in English ports the work done and the expenditure of coal practically agreed. Using Atherton's rule, namely the cube of the speed multiplied into the two-thirds power of the displacement, and divided by the hundredweights of coal per hour, a certain constant was obtained; and that constant, for a speed of 9 knots an hour, was practically correct at 12,400 for north-country coal, and at 13,500 for Welsh coal. But when vessels proceeded to the Mediterranean, or to the Indian ports, and there took coal on board, the constant often fell as low as 8,000, when worked out in the same way; showing clearly that the full weight was never supplied, unless very great care was taken to obtain what was actually paid for. In one instance the constant showed during one voyage 14 per cent. short weight, and the report was sent to the captain and engineer of the steamer. The ship went on the same voyage again, and instead of having 14 per cent. or 160 tons short in a seven months' voyage, there was less than 3 per cent. unaccounted for. That was a matter which ought to be taken into consideration, when shipowners came to examine their coal bills.

Mr. Samson Fox thought from what the author had said, p. 468, that he was rather in the dark as to the number of corrugated flues which had been made. They had now been made to the number of 3,700, two-thirds in marine and one-third in land boilers, and the number of failures amounted in all to eight. One steamer and two land boilers had given out in the flues; a flue had

collapsed on account of being red hot; another on account of running very short voyages, and not being sufficiently washed out. The oldest flues had been at work about four years; therefore with regard to the question of endurance there was, he thought, sufficient evidence. With regard to the evaporative power, he could give a comparison of one or two large steamers, indicating between 3,000 and 4,000 horse-power. In the case of two steamers built exactly alike, except that one had plain furnaces and the other corrugated furnaces, the indication of the former was a little over 3,500 horse-power, and of the latter just 4,000 horse-power. In the case of another pair, the difference in favour of the corrugated furnace was about 450 horse-power out of 3,750. Then as to economy, there was a steamer which had been running a voyage of something like 12,000 miles for about three years: the area of the fire-grate in that set of boilers was 273 sq. ft., and the horse-power indicated was 2,677; the mean speed of the ship was 13·1 knots per hour, and the consumption of fuel over the whole of the time was 1·67 lb. per I.H.P. per hour. With regard to land boilers, a very accurate test had been made in Germany: a boiler 30 ft. long, 7 ft. 2 in. diameter, and with a flue 4 ft. 3 in. diameter, with the feed-water at 131° Fahr., evaporated 10·85 lbs. of water per lb. of coal, at a steam pressure of 75 lbs. per sq. in. After that an experiment was tried by shutting off the external flues at the sides of the boiler, and using only the 30 ft. corrugated flue; the evaporation was then 8·175 lbs. of water per lb. of coal, or nearly 6 lbs. of water per sq. ft. of flue surface per hour. The corrugated flue, both in its manufacture and in its use, had presented difficulties which were not easy to be got over, from the material first used having been iron; and he was satisfied that, unless he had taken to mild steel, the corrugated flue would have had many difficulties to contend with, which had now been got rid of. Iron manufactured in large plates could not be thoroughly homogeneous. The best method of making iron, up to the present day, was that of puddling and piling slab moulds one upon another and welding; and its success depended on the complete welding up of all the original surfaces of the slabs. Now a plate sufficient to make a flue of 16 cwt. required a pile of at least

20 slabs weighing 1 cwt. each, and each having a surface of about 3 sq. ft.; and it would be found a very difficult job in practice to get rid of those 60 sq. ft. of surface, so as to have a homogeneous plate. But with mild steel an ingot was taken, in which the particles had never separated since they had come together in the mould; and the only difficulty was in the ends. He had made above 2,000 tons of steel ingots into corrugated flues, and not five plates made from those ingots had been rejected, though every plate had been tested by the Board of Trade.

Mr. Jeremiah Head, referring to the paragraph (p. 466) "If the evaporative performance of the marine boiler is to be increased, it must be by one of the four following methods," thought perhaps a fifth might have been added, namely a greater difference of temperature between the inside of the fire-box and the water spaces. Every one knew that if two bodies at different temperatures were in contact, the heat passed from the one to the other with a velocity of transmission varying as the square root of the difference between the temperatures. In drawing attention to the saving of fuel which had been effected during the last nine years, the author had pointed out that the mean pressure used had increased from an average of 60 lbs. to something like 100 lbs. Now, inasmuch as water or steam at 100 lbs. pressure was of a considerably higher temperature than water or steam at 60 lbs., it was clear that, if the temperature in the fire-box was not altered—the method of burning the coal remaining the same,—there was now actually less difference than before between the temperature of the fire-box and that of the water to which the heat had to be imparted. Therefore it would be strange if the boiler had even maintained its efficiency during this period, seeing that there had been less difference of temperature for the transmission of heat. Evidently this point had been perceived by the author and some of the previous speakers, because they advocated strongly a forced blast, which meant a higher temperature in the fire-box; but it did not appear to him that that was clearly brought out in the paragraph, p. 466. He should therefore like to suggest that the reason why the forced blast was so likely to be the real direction of

improvement was that every square foot of heating surface would thereby become very much more effective, because of the greater difference of temperature, and the greater velocity in transmission of heat, thereby produced. If higher pressures were to be used, and therefore higher temperatures of water in the boiler, it was clear that the way in which progress must be made in efficiency was by getting a higher temperature in the fire-box; and the best way at present known for doing this was by means of a forced blast.

There was another direction in which he was sanguine that something might be done at some future time. Every ton of air that entered the fire-box was composed, roughly speaking, of about one-fifth oxygen and four-fifths nitrogen. That nitrogen was inert and useless; it entered the fire-box say at a temperature of 50° Fahr., and left the funnel afterwards at 600°, and it was clear that the whole of the heat taken up by it as it passed through the fire-box and tubes was entirely lost. A plan was needed, which should save passing that useless nitrogen through the fire-box. He believed some experiments had been made some years since, to see if ordinary atmospheric air could not to some extent be filtered of the nitrogen, by passing it through something which would take a little of it away, so as to leave the air that had passed through richer in oxygen than before. It had been found that by passing air through very fine membranes of a certain kind the nitrogen was stopped more than the oxygen was. Perhaps, if it could not be done in that way, it might be done by artificially mixing the air to some extent with oxygen before it entered the ash-pit, in such a way as to increase its richness. Or there was still another way in which the same end might be reached, namely by some regenerative system. If the air which entered the ash-pit could be heated beforehand by the waste heat from the funnel, it would effect what was needed by lessening the total amount of heat which was run away with by the nitrogen.

Speaking of the joints in a boiler, Mr. Parker had said that if the external rings of the boiler could be rolled solid, without any joint, 25 per cent. more pressure might be used, because the joints were never more than 75 per cent. as strong as the solid plate. He would suggest whether Mr. Parker did not forget the crossing of

the joints. Supposing the whole length of the boiler was made of four rings breaking joint, the boiler was not weakened to the full extent of the difference between the joint and the solid, but only by something like half that difference, or 12½ per cent. Mr. Parker had also spoken about the factor of safety which should be allowed for thick and for thin plates; but he would ask whether he had considered that thick plates, whether in iron or steel, were not quite as strong (so far as they now knew how to make them) as thinner plates, on account of the smaller amount of work, relatively, which it was practicable to put upon them; and therefore whether the factor of safety should after all be altered. Mr. Parker had also said, with regard to the factor of safety of 6, that it had only to cover the corrosion. But he would suggest whether it was not the elastic limit which should be considered, and not merely the ultimate tensile strength. If it was true, as had been shown at the last meeting (Proceedings, 1881, p. 209), that steel began to stretch permanently at only a little over 8 tons per sq. in., which was something like one-fourth of its ultimate tensile strength, then, inasmuch as they must not exceed or even come near that elastic limit, he would ask whether 6 was really too high a factor of safety.

Mr. T. R. Crampton said the author had brought the subject forward in a very clear way, in expressing his views as to what should be done in the future. But in one point he had not done what he ought to have done—namely to separate the boiler from the engine. He did not see how any satisfactory judgment could be formed unless these were separated. He had known cases in which good engines had been condemned in consequence of the boiler, and the converse. About forty years ago he had made experiments with 40 lbs. pressure and about six grades of expansion, on a double-cylinder compound engine well jacketed, and everything attended to as well as it was in the present day; and one I.H.P. was obtained from 18 lbs. of water. He felt convinced that practically 11 lbs. of water would very shortly be evaporated with 1 lb. of Newcastle coal. It was simply a question of regularity of firing; and that had not been touched at all. There should be some mechanical means of

firing. As to the reduction of nitrogen, which Mr. Head had suggested, he believed if the nitrogen were reduced they would have too much heat. If the proper proportions were kept, namely 12 lbs. of air to 1 lb. of fuel, they might even now have a temperature so high that they might prefer to reduce it if anything.

Mr. Holt's idea of having a single engine deserved great consideration. Of course the double engine would naturally give a more equal motion; but if engineers could practically get what they wanted from the single engine, by all means let them keep to it, up to the maximum which it could do. With the single engine the expenses were reduced in a variety of ways, and every part could be got at better. His conviction was that they ought not to look always to the consumption of fuel, but also to the cost of repairs at the end of five or six years. There were many things to be done besides burning fuel.

With regard to the question of condensing, he might point out that the passing of water through the condensers by pressure gave a better result than by sucking it through. Some experiments which he had made on a marine boiler, with 1,500 sq. ft. of heating surface, showed 10 per cent. more water evaporated by the use of air under pressure than by the vacuum of the ordinary chimney draught. He had tested the quantity of the gases passing through all the tubes, and had found that in the case of pressure all the tubes were being supplied with the proper quantity of gas, while with suction a large number of the tubes had hardly any gas passing through. The suction of the chimney drew all the gases by the nearest path. There was also another practical advantage when cleaning out the tubes. In the case he had mentioned he had found that, having a pressure of only about $\frac{1}{2}$ inch of water in the fire-box (working with dust-fuel), the smoke-box door could be opened and the tubes cleaned out while working, and the evaporation was only 10 or 15 per cent. less than when working at a maximum with the smoke-box door shut.

From experiments which he had made upon the subject, he believed there was a future for self-acting firing, thus doing away with the dreadful work of the firemen; and that 11 lbs. of water would then be practically evaporated from 1 lb. of coal, as he had done over and over again with self-acting firing, and with dust-fuel. The

difficulty he had experienced had been in the lining of the fire-box; the great heat destroyed the bricks to such an extent that he had discontinued the experiments. Since then however he thought he had discovered a self-acting lining which could be recuperated, and made practically indestructible. If a revolving fire-box were used, as the bricks wore away they got to a point where the water kept them cool; and if the brick lining was knocked off it was replaced by the slag. If dirt was put in, it would melt, and accumulate in the chamber until it ran over, the dirt in the coal being sufficient for the purpose. There would always be a lining of slag in the chamber; and this was necessary if they used dust fuel. They simply wanted a plain cylindrical boiler, filled with tubes like a locomotive boiler, and having the revolving combustion chamber in the front of it: like his revolving puddling furnace (Proceedings, 1876, Plate 43), where the slag formed a permanent lining. This system of revolving chamber had proved to be almost indestructible in puddling; and was therefore quite adapted for boilers. The form of such a boiler as now described was very simple, and it was excessively strong. He only mentioned the matter to show that under such conditions they might have a perfect self-acting apparatus. The climate was a matter of no consequence; they might start from England and go to Calcutta, and if they wished to burn say 1 ton of coal an hour, they could burn it within 5 per cent. on the whole journey without any one touching the apparatus. He might observe that too little attention had been given to this question of self-acting firing; there had doubtless been many failures, which discouraged steamship owners. The problem was not easy to solve, particularly where fire-bars were a requisite; but with dust-fuel and a revolving fire-box it was, in his opinion, quite possible to effect the object.

Mr. E. Reynolds wished first to acknowledge the kind way in which Mr. Marshall had mentioned cast-steel propellers: he had been the first to adopt them for ocean ships, and he had been a steady friend to them ever since.

Referring to the question of the single engine, it was practically impossible to put into a ship a fly-wheel which would give an equality of power with an engine of 5,000 or 6,000 H.P. It was

difficult enough to get proper work out of a propeller, even when it had uniform power on it throughout the revolution; and he was satisfied that no fancied simplicity of a single engine would compensate for the disadvantage of applying the power to the propeller by irregular efforts.

With regard to boilers, in the presence of so many marine engineers he did not wish to say much; but there were a few fallacies on that subject to which he wished to call attention. First of all, the disposition to exaggerate the advantage of the locomotive type of boiler was again on the increase. The locomotive boiler he believed was the best for its particular purpose, but its special conditions must be borne in mind. One of these doubtless was to burn a very large quantity of fuel in a small space; and this was becoming daily more desirable in steamboats, as the author had pointed out. But a locomotive boiler was washed out say every two days, and properly looked after; and that condition failing, he did not think that a boiler, with spaces so very narrow as to enable the surface to be concentrated in the way it was in the locomotive, would do at sea: but where the circumstances were such as to admit of crowded heating surface, with very narrow water-spaces and no possibility of internal examination, then other forms of multitubular boilers could be so arranged as easily as the locomotive form. Next, the thinner plates which were used in locomotive boilers, with a lower factor of safety than the Board of Trade required for marine boilers, would not be admissible at sea without constant or very frequent attention. He seldom heard a paper of that kind read without hearing attacks on the factor of 6, as required for marine boilers. He could only say he should be sorry to buy any part of a marine engine in which he imagined there was a lower factor of safety than 6, even though so much did not depend on the failure of the engine as on that of the boiler. There was another practical point, namely that when it was attempted to make a boiler of that class to any considerable size—such a size as the marine service would require — the difficulties already felt by locomotive superintendents would become exaggerated. The locomotive fire-box with its flat sides, which could not expand in any way without

some buckling, was not now the durable affair it used to be when it was only 3 ft. square; and the difficulty would keep increasing as the flat sides became larger. He was aware that Mr. Fox had proposed to corrugate those flat sides, something after the fashion of the corrugated flues; but he could not, with the flat sides, get the yielding in every direction that he did get with the cylindrical flue.

With regard to the best type of boiler generally, the effort to reduce the diameter of the shells was by no means new. He remembered Sir Frederick Bramwell many years ago constructing some boilers with small shells and water legs. But one thing which should be borne in mind was that it was not sufficient for the boiler to have merely a certain amount of heating surface in a small space; there must be also a certain area of water surface, especially in a ship tumbling about at sea. Mr. Marshall had called attention to that point, and had claimed it as one of the advantages of the navy boiler, as it unquestionably was; but he seemed to have lost sight of it again a little, because in his proposal to introduce the locomotive type he had mentioned that steam space might be got by raising the crown of the external fire-box. That was not the same thing: steam room and water area were not interchangeable advantages.

Mr. D. ADAMSON said the point in the paper which specially impressed him was the selection of the type of engine. He thought it was only fair that they should acknowledge amongst themselves the great progress that had taken place during the last nine years, since Sir Frederick Bramwell's paper had been read. It was stated in the present paper that there had since been an annual saving of $1\frac{1}{2}$ per cent., or $13\frac{1}{2}$ per cent. gross in all; and it had been verbally stated, since the paper was read, that the saving was really equal to 2 per cent. per annum. The saving, if it went on at that rate, would be very great, and must end in a very economical consumption of fuel before many years were over. On the type of engine the goodness and the success of a ship greatly depended. The subject had been before them in 1880 at Barrow, and the triple engine had there been recommended; but he thought that Mr. Marshall spoiled his

paper in some degree by the value he attached to Mr. Holt's letter. For if one cylinder were used to produce the force necessary for propelling a big ship, say equal to a percussive force of 100 tons on the steam piston, was it practical or sensible to bring such a force on a single crank-pin, when it could easily be divided over three cylinders, letting each have a force of only 33 tons? While they got triple security in the triple engine, they would not diminish by a fraction the ultimate strength of the screw-shaft, because that was wanted to contend with the full power of the combined engines. But if it were wished to get the highest possible proportion of power, that would be most easily accomplished, as had been wisely suggested, by a much increased speed of piston. He held that this was the great and only principle to act upon—to augment the bearing surfaces, and to diminish the percussive action and the frictional load on the crank-pin as they increased the speed. It was no supposition, it was a demonstrated fact, that the faster any machine went the less force must there be on any given point of wearing surface. As to the question of three cylinders or one cylinder, he held that one cylinder was an inadmissible and an obsolete arrangement. If they looked at the matter according to the one-sided view that Mr. Crampton had put before them, they would at once jump to the conclusion that simplicity was everything; but could any one control the laws of nature and turn them to his own convenience at will? If they began with a high pressure at one end of the stroke, and ended with only atmospheric pressure at the other, the difference of temperature within the one cylinder would preclude any possibility of the economical application of the steam.

It might be remembered that he had read a paper before the Iron and Steel Institute (see Journal 1875, p. 360) on quadruple action, or engines to use steam four times over; and if he were to prophesy with regard to the results, he should certainly prophesy success for quadruple action, with a continuous run-through of the steam from cylinder to cylinder. First, nature was on his side. The temperature was only lowered in a slight degree in each successive cylinder. Beginning say with 100 lbs. to 120 lbs. on the first piston (which was his common practice), the pressure on the second piston would probably

be about 60 to 65 lbs. The reduction in temperature in any one cylinder was very much less than could possibly be the case if the entire expansion took place in one cylinder, when commencing with 120 lbs. pressure ; and although there must be some loss between the cylinders, both in pressure and in temperature, it was only slight: while on the other hand the four pistons would check any loss through leakage of steam direct into the condenser, which must take place with one cylinder when either the piston or the slide-valve leaked. Beyond this, he held to the grand principle of Dalton's discovery, and Gay-Lussac's in France—in the same year 1801, although unknown to each other—that by increasing the temperature of gases 480° Fahr. their volume was doubled. Now multiple cylinders gave facilities for superheating, which were impracticable in the single cylinder. Superheating high-pressure steam could only end as it had done, in extreme failure, since high-pressure steam was necessarily hot steam, and they did not want to make it more impracticable than it already was in that respect; but with the multiple-cylinder system the low-pressure steam could certainly be practically superheated to the temperature of high-pressure steam, whilst the expansion was going on, and concurrently with the reduction of pressure ; and thereby considerable economy could be secured in the multiple system, over and above the single-cylinder plan. Steam at atmospheric pressure, or 212°, might be heated up to the temperature of high-pressure steam, or at least to 360° ; and superheating became in this way not only practicable but highly economical. Thus they were enabled to utilise Dalton's grand law, and to increase the bulk of the steam at much less cost than by any other means.

Passing on to the consideration of the boiler, the most injurious condition set forth was that of corrosion. He regretted that the paper to follow, on iron and steel for ships, had not been read at the same time as Mr. Marshall's, because it was impossible to consider at all the question of the application of mild steel or iron, without discussing the conditions attached to shipbuilding; but he would treat of this when Mr. Price's paper came to be read.*

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* See discussion upon "Iron and Steel for Ships," pp. 571–4, *infra*.

The subject of riveted joints was of vital importance in connection with steam boilers. But the strength of the joints, in the marine boiler especially, was not of equal importance throughout; there must be one class of joints for the shell, and another class of joints for the fire-box. With regard to the joints for the shell, it was of no importance to consider the quantity of metal requisite to unite the plates, in order to get up to the maximum strength. The principal thing was to get uniformity of strength throughout. On that head he was inclined to think that the corrugated flue had been rather too strongly put forwards. It had some advantages and some disadvantages, but he would only look at it for the present with regard to the condition of a fire-box which was subject to getting red hot, and needed to have security under those extreme conditions. The corrugated flue, they were told, when red hot collapsed and went down. But in place of corrugated flues, Adamson's flange seams might be used, which might be made as numerous as was wished, and with this difference: that the metal between the flange seams would withstand the force of the pressure, let that pressure be what it might, either at red heat or comparatively white heat, the flanges forming as it were a back-bone between the intermediate plates. Security could thus be obtained, because of the quantity of metal in the flanges that was kept away from the fire, and was exposed only to the temperature of the steam.

Mr. Marshall said he must thank the members cordially for the very candid and friendly manner in which his paper had been discussed. Of course he knew that it had run counter to the views of several friends present, notably perhaps Mr. Crampton, who was always against high pressures. He would now endeavour to reply to the various questions that had been raised by the several speakers.

First he would thank Mr. Kirk—who he supposed might be looked upon as the representative of the Glasgow engineering and ship-building community—for the remarks he had made. It was satisfactory to find that he approved of pressures of at least 120 lbs. He himself did not think there was much gain to be got beyond that pressure, or 150 lbs. at the outside. The practical difficulties then

became so great—as had been seen in the Perkins engine so ably reported upon very recently by Sir Frederick Bramwell—that there was clearly a limit to high pressures. Owing to the multiplication of cylinders, and the difficulty of dealing with high temperature, no higher result had been there found with 390 lbs. than was now obtained every day with 90 lbs. pressure.

Mr. Kirk had raised a question to which attention had also been called in the paper—the question of dead-weight capacity instead of measurement capacity; and had mentioned that there were vast numbers of ships that did not measure their profit by dead weight at all. That was quite correct; but, while there were a great many that never went by dead weight, a large proportion of steamships did, as for instance all the Transatlantic steamers, all the vessels going along the coast, and ore- and grain-carrying vessels, of which there were a large number. In those cases, wherever a ton weight was saved in machinery and in water carried, there was £10 per annum advantage to the shipowner.

Mr. Kirk had also remarked that light engines must necessarily be costly; and he agreed with him. There was not a manufacturing engineer who would not agree that, where they had to use steel and to go into appliances involving a large amount of manufacture and manual labour, the work must be more costly than where they could deal with a heavy casting, which could be taken out of the foundry and simply dropped into its place. Still, if a lighter engine could be constructed, as Mr. Kirk had constructed the engines of the *Nelson* (which he believed was a very satisfactory ship), and if Mr. Thornycroft was right in adopting a system of working engines at 600 revolutions per minute, or at 440 in first-class torpedo boats—if that could be done, it was worth doing. The weight was worth saving, and he thought there was a field open for the engineer's skill and ability in that direction. It was a purely mechanical step. It might be costly, and the shipowner would have to pay for it; but supposing a pair of 200 horse engines, suitable for a ship of 3,000 tons dead weight, were to cost £1,000 more, and would save the owner £1,000 a year, then he would get the additional expense back in twelve months, with the advantage of the permanently higher profit subsequently.

He was glad to find that Mr. Kirk concurred in his view in reference to the locomotive boiler. Perhaps while referring to that subject it might be well to go into the several questions which had been raised respecting it by the various speakers. The basis on which he had gone was that of efficiency and reduction of weight, with a view of making the marine engine more profitable to the owner. Now, if a locomotive boiler could be adopted for a vessel of say 3,000 tons, requiring engines of 1,500 indicated horse power, as in Plate 71, where the dotted lines showed the space required for boilers of the ordinary type, it would be seen that the locomotive form would save the space A at the fore end, Fig. 40, and also a considerable amount at the sides, Fig. 39. It would save at least 150 tons of cubic capacity in that particular ship, the *St. Dunstan*; and that saving meant of course £1,500 a year to the shipowner.

With regard to the question of water surface, raised by Mr. Reynolds, the water surface in locomotive boilers would not be much less than in the navy form of equal power. The three locomotive boilers shown in Plate 71 had together 242 sq. ft. of water surface, while boilers of the navy form, for the same power, would give about 300 sq. ft. He did not anticipate any difficulty whatever in getting dry steam, bearing in mind locomotive practice, where there was no very serious difficulty with priming or with wet steam. The large steam-chamber D in the locomotive boiler, Fig. 40, was carried with a view of taking the steam off at as high a point as possible, about 6 ft. above the water level.

He should have been glad to hear at greater length the views of members on the subject of forced draught and the mode of applying it. The part S in Fig. 40, Plate 71, would be the enclosed stoke-hold, where the men would have to work under pressure from the blowing fans FF. He did not anticipate that the pressure required would be more than $1\frac{1}{4}$ in. of water column, as in the case of the vessels with forced draught alluded to in the paper, p. 469; which, added to the funnel draught, would make an effective pressure of $1 \cdot 65$ inch. The men there worked six or eight hours at a time, without difficulty.

Mr. Crow had stated that the Woolf engine was as efficient as the receiver engine. No doubt there was a difficulty in saying why it

should not be so; but the fact was that it was not, if judged by the coal consumed and power indicated. A glance at Table I. (p. 452) would show that the results given for the B (Woolf) and C (receiver) classes of engines differed by exactly 10 per cent. in favour of the receiver class: thus confirming Mr. D. K. Clark's deductions from experiments conducted by the most trustworthy American and French engineers. The difference in actual working on long sea voyages was thus 10 per cent. He did not say that that was all loss in the Woolf engine; but in his opinion there were no cases in which that class of marine engine was preferable to the receiver engine, in regard to efficiency.

Sir Frederick Bramwell and Mr. Rich had been inclined to call in question the correctness of Table I. The data were obtained in this way. He had drawn out a form, and sent it round to a large number of manufacturing engineers, shipowners, marine superintendents and others, who returned it to him with the data filled in. He had merely asked them to give the best results they had obtained in recent practice in long-voyage ships; and they had supplied the information which he had embodied in the Table. On some occasions, where he had felt doubtful as to the results, he had written a second time about them. When he had received a statement of indicated horse-power in very round numbers, such as 700, 800, or 1000, he had thought the figure questionable, and had taken the liberty of either rejecting the ship from the list, or calling the attention of those sending the information in order that they might correct it. But in nearly every case the data were so satisfactory that he could not call them in question. The form returned to him was accompanied in many cases by indicator diagrams, giving the steam-pressures and the revolutions of the engines; and also by the logs of the vessels themselves on long voyages. If the revolutions and the indicator card corresponded with the average of the work as recorded in the log, he took that as the soundest and best datum that could be had for the final result. He thought the Table might be considered as giving, not, as Mr. Parker had said, the highest results obtained, but average results, which might be regarded ten years hence by his successor as accurate, in the same sense as he himself regarded those given by Sir Frederick Bramwell.

With reference to Mr. Perkins's system of tubulous boiler, referred to by Mr. Rogerson and also by Sir Frederick Bramwell, it was clear to him that that boiler had something wrong about it. If there was a pressure of 390 lbs. in the boiler, and only 295 lbs. in the cylinder, then there must be something wrong somewhere. Then again, in multiplying cylinders and passing the steam from one to another, there seemed to be enormous losses going on between them. Mr. Adamson had called attention to the advantages of multiplying cylinders; but there were certainly also disadvantages attending the plan, and he thought Mr. Perkins had experienced them. At any rate he himself did not see what good was to be got by adopting Mr. Perkins's form of tubulous boiler, if the result was only to be very similar to that generally obtained with the ordinary form of marine boiler. The difficulty which he saw was that of getting dry steam. Water was carried over with the steam, and efficiency was lost.

Mr. Parker had called attention to some remarks in the paper as "complaining of restrictions." He was not aware that he had complained. He thought the Board of Trade was a very useful institution; and Lloyd's also, especially so long as it was managed by Mr. Parker. He had merely referred to the fact that there were certain restrictions, and that so long as those restrictions remained there was a difficulty in adopting very freely the locomotive or any other form of boiler. He would give an example. If they were to take the locomotive boiler of to-day, working regularly on the railway (as Mr. Kirk had said), among thousands of people, at 150 lbs. or 180 lbs., and were to ask the Board of Trade to pass it, they would pass it at something like 90 lbs.; so that half the pressure would be lost. He did not say that Lloyd's were right or wrong in so doing; but it was a restriction.

As to corrugated flues, he thought they were a step in the right direction. He had himself been singularly unfortunate in the use of them, and he had mentioned in the paper the causes of failure. He believed these had not been due to the corrugated principle, but to the difficulties which Mr. Fox himself admitted had been met with in the manufacture. These Mr. Fox was now rapidly

overcoming; and when he had got his mills to work, and could manufacture the flues by rolling them, as was being done by Krupp at Essen, instead of hammering them as at present, a good furnace would be obtained by the corrugated system, if it were not superseded beforehand by the locomotive boiler.

With regard to the question of the single engine and Mr. Holt's letter, he had called attention to that letter because Mr. Holt was a gentleman well known to many of them as a very advanced shipowner, who did not hesitate to spend his money and use his vessels in experimenting, so as to bring about the best possible results. He perhaps took therefore a broader view than many marine engineers. He worked the ships himself, and had the question of expenses and repairs constantly before him, as well as the coal account, which he called a minor disbursement; and so long as the engine was managed by him, or by their esteemed friend Mr. Crow under his direction, it seemed to do very good work. Mr. Holt did not attempt anything like a high economical result; he said he did not seek it. He did not know that Mr. Holt was right there; perhaps he was not. A shipowner might as well have the £10 per annum if he could, instead of the ton of coal to carry; but Mr. Holt did not seem to care for it, and they must leave him to his opinion.

ON PRINTING MACHINERY.

By Mr. JOHN JAMESON, of Newcastle-on-Tyne.

The only papers relating to Printing Machinery recorded in the Proceedings of the Institution of Mechanical Engineers are one in 1863 on type composing and distributing, and one in 1865 on bank-note printing. The author is therefore led to hope that, in a path so untrodden, the present paper may afford features of interest, without attempting to give full technical information on the subject.

About five years ago, the proprietors of the *Newcastle Daily Chronicle* gave an order to Messrs. Hoe and Co., Printing Machinery Engineers of London and New York, for a larger and more complete newspaper printing machine than had ever before been attempted. The author was entrusted with the design of the engines and boilers, and with the arrangement and carrying out of the various mechanical details of the office, and has been thus occupied until the present year, when the whole has been erected and completed. It is this printing machinery of which he proposes chiefly to speak; and by the kindness of the proprietors of the *Newcastle Daily Chronicle* he is able to invite the members of the Institution to see it in actual operation. In order however to bring before those who have not given special attention to the subject some idea of the advances made in recent years, and of the peculiar merits of the machinery specially to be described, he proposes, without entering into anything like a history of printing, to refer to printing machinery of more than one kind. This must be done hurriedly and imperfectly, owing to the largeness of the subject.

It would not be possible in any reasonable time even to outline the variety of machines in use for letterpress printing alone; still

less to institute a comparison between the merits of the various machines employed at the present moment. The author therefore will merely make a general and imperfect classification of printing machines into three large groups, namely Platen machines, Cylinder machines, and Rotary machines. Of these the Platen machine is one in which the paper is brought down as a flat sheet on a mass of flat laid type; the Cylinder machine is one in which the paper is wound on a cylinder, and pressed upon flat laid type by the revolution of that cylinder; and the Rotary machine is one in which the type is itself placed on the periphery of a cylinder, and with it revolves in contact with the paper, which is wound on another revolving cylinder.

The author will dismiss in a very few words, for brevity's sake, the consideration of the Platen and Cylinder machines. Each machine has special advantages and disadvantages. In high-class book printing it is of the greatest importance that the most perfect clearness should be obtained, and the very slightest movement of the type or paper during any period of their contact is of course fatal to the best results. Again, seeing that absolute perfection of level in type and tables is not attainable, and that a print taken on perfectly flat paper from an uneven forme would give a variety of impression objectionable for high-class printing, a process called "making ready" is required, which consists in underlaying the sheet of paper to be printed with something to compensate for inequalities of surface in the type, so that a uniformly deep impression may be obtained. Bearing this necessity in mind, we can realise to some extent the extreme importance of accurate "register"; by which is meant that the two surfaces, so adapted to each other as to give at all parts uniform impression to a body so thin as a sheet of paper, should meet, every time they come together, precisely as they are arranged to meet and not otherwise. Especially is this important when woodcuts or other illustrations are embraced in the matter to be printed, seeing that these require the most careful and accurate underlay and register, to give a really good result. It is hardly necessary to say that, other things being equal, the greatest accuracy may be obtained by a perfectly flat impression on a perfectly flat and motionless table, and

hence that the Platen machine in one of its many admirable forms should be used for the finest work.

It is often however of great importance, and especially in the case of periodical literature, that a rapid rate of production of copies should be obtained; and it is further important that this reproduction should be secured with as small an expenditure as possible; and thus high finish and extreme accuracy must be somewhat sacrificed. As in steel engraving the artist's proof is succeeded by the proof after lettering, so in letterpress printing, for more rapid work, the Platen gives way to the Cylinder machine. In the Cylinder machine both cylinder and type are moved during the progress of the impression, with the risk of slight variations in the simultaneous movement, and therefore of some defect in impression; and with the further risk of less accurate register, or less perfect coincidence of the adapted surfaces. These risks are compensated and provided for to a very great degree by many most ingenious devices; but with every appliance and provision it is yet impossible to combine great speed of production with the highest accuracy and beauty of result.

The third group of letterpress printing machines are formed by the Rotary machines, in which cylinders are employed both for type and for impression, and in many of which newspapers are printed from continuous rolls of paper at a rate of production, which a very few years ago would have been regarded as altogether incredible. One of the first and most important requisites for the efficiency of a quick running rotary machine is the use of stereotype plates instead of type. If ordinary type were used, then, even if the difficulty of setting it in a circular form could be quite obviated, and if it were then so tightly bound in its place as by the pressure almost to elongate the type, yet the alternate action due to centrifrugal force in one direction and the pressure of the impression cylinder in the other—combined (if the type cylinder was horizontal) with the action of gravity on a weighty mass of type, alternately tending to open and close the arch into which the type must be built—these, with the jar and shake to which the movement of the machinery would necessarily subject it, would involve extreme risk of the whole forme of type

breaking loose. Besides, if the printing was done from a type forme, the whole edition must be printed from that forme, unless a duplicate was set up—an expense too great to be incurred; and the production would be proportionately slow. By stereotyping however any number of duplicate formes can be obtained; and thus double printing machines, and many of them, can be employed simultaneously in printing the same paper.

The fundamental requisite for Rotary printing machinery may therefore be said to be the use of stereotype plates. The process employed in the production of these plates is so simple, rapid, and inexpensive, the results are so absolutely perfect, and the multiplication of copies is so easy (a matter of the utmost importance), that it appears to the author any effort to overcome the difficulties just referred to, as pertaining to the use of type, would be entirely misdirected.

Rotary machines for newspapers are made on two systems, in one of which the paper, in separate sheets, is supplied to the machine from a number of tables in succession, and printed on one side; it is then usually transferred to a second similar machine, to be printed on the other side by a second similar process. In the other system the paper forms a continuous roll, which is printed on both sides and separated into sheets by the action of a single machine.

In order to describe the machinery of the *Chronicle* office to the best advantage, it will be convenient first to give some account of the operation and arrangements of a newspaper office before presswork begins; then to describe the printing machinery; and thence to trace the newspaper to its delivery as a completed article.

Without actually seeing it, it is difficult to realise the scene of activity presented in a daily newspaper office from nine or ten at night till the hour of publication; and the extent to which the most careful organisation and the most exact discipline and method contribute to achieve rapidity of execution without hurry, and an enormous accumulation of work without confusion. About nine o'clock at night, with the exception of a few repeated advertisements kept standing from the previous day's issue, not a type of the paper has

been set. There is a considerable accumulation of "copy" however, which is distributed in detached portions to a large number of compositors. The compositors work with no great rapidity of movement, apparently indeed with great deliberation; it is found however that the best result is by no means necessarily associated with apparent rapidity. The detached portions of the earliest copy, on being set up, are brought together in the form of a part of a column. Slip proofs of this are taken from the type itself, in a small hand press in the compositors' room. The slip is compared with the copy by readers in separate side offices, one reading aloud from copy with great rapidity and close regard to new sentences, capitals, stops, and verbal accuracy, but apparently with the most entire disregard of the meaning conveyed; and the other correcting the printed slip. The corrections (wonderfully few in number) are made in the forme; and it passes to another table for arrangement into columns, and then into pages.

The first pages are usually advertisements; and as arranged they form a level sheet of type on a level iron table. There they are locked securely by screws and wedges into a frame or chase, which enables the whole to be safely handled without risk of displacement. As each page is thus completed, it passes to the stereotype room. There a wet sheet of a species of papier maché is laid over it, covered with a spongy blanket, and this is pressed into the forme of type by being passed through a roller press, which ensures accurate contact with the surface and recesses of the type at every part. It is then covered with a somewhat elastic blanket pad, to retain contact and to allow the escape of steam, and the whole is placed in a powerful screw press, which is at the same time heated by steam. In a very brief space of time the moisture of the papier maché is driven off, and a matrix of something like cardboard is produced, deeply indented by the type, and presenting the letters as we see them when printed.

This papier-maché matrix is bent into a circular shape in the direction of the height of the page, and is placed in a mould having the required curvature. This mould swings upon trunnions, and has a hinged cover, fitting accurately at the sides and bottom and with an opening left at top, which hinged cover can be

shut down and well secured to the case. When the mould is thus closed, with the paper matrix within it, it is placed in an inclined position on its trunnions, and a ladleful of melted type-metal is poured in through the opening. The metal almost instantly sets; the mould is opened; the casting is slightly swabbed with damp cloths, to correct the brittleness due to its heat, and is then removed to a sort of saddle furnished with planing appliances and revolving cutters. Here the edges are trimmed and bevelled; and, if any large blank spaces exist, where the elasticity of the inking rollers, or of the blanket on the impression cylinder, afterwards to be described, might produce an undesired impression, some extra cutting out of the centre of such parts is performed. The stereotype plate thus formed is then ready for the press, and passes by a hydraulic lift to the machine room, where it is placed on the machine. Any further number of casts from the same matrix, that may be desired, are made in the meantime, and follow in succession.

While the first pages are being made up, stereotyped, and placed upon the machine, copy for the later pages is continually accumulating, in the shape of superabundant supplies of Press Association telegrams, a continual current of private-wire despatches, transcripts of notes or telegrams from "our own reporters," stereotyped weather chart and forecasts arriving by train from London, leading articles, &c., &c. A selection and condensation of these supplies having been made, and the copy distributed, a continual inflow of type, and repetition of the process already described, goes steadily on. As the time of publication draws near, the compositors work shorter strips than at an earlier part of the night, so as each to spend a comparatively short time on the latest news, and to set up the last columns with great rapidity. With the first pages of the newspaper there is no extraordinary press in the stereotype room: but with the last page the operation is timed to a second, and recorded for the manager daily. No expense is spared, and no expedient by which a moment can be saved is neglected. As a result it is on record that, from the arrival of the type in the stereotype room to the departure of four finished stereotype plates to the machine room, including all the operations described, only

twenty-five minutes have been required, the second and following plates requiring only three minutes each for their completion.

As the stereotype plates are completed, they are attached to the cylinders of the printing machine, and secured firmly by their bevelled edges, by means of sliding cramps worked by screws. When the last plate is attached the press is ready for work. The printing machine at the *Chronicle* office consists of two type cylinders A_1 A_2, Fig. 1, Plate 72, 7 ft. long and 4 ft. in circumference, on which the stereotype plates are fixed; and of two impression cylinders B_1 B_2, of equal length, and covered with fine blanket over india-rubber, which serve to press the paper against the type. Each of the type cylinders is furnished with a train of inking and distributing rollers C C, composed of glue and glycerine mixed in certain proportions, so as to ensure the requisite tenacity and elasticity, and also a peculiar character of surface necessary for the proper distribution of the ink. These rollers are driven by surface friction on the type cylinder, and have therefore a surface speed equal to that of the type cylinder. They have each, in addition to this rotary movement, a reciprocating or waving movement in the direction of the axis, so as more perfectly to distribute the ink. The inking rollers are supplied by means of an intermediate roller I from a ductor roller D working in an ink reservoir. The intermediate roller I is alternately in rapid rotation and nearly at rest, as it is made to oscillate at short intervals from contact with the inking rollers, which rotate very rapidly, to contact with the slowly moving ductor roller. The supply of ink to the ductor roller is regulated at short intervals along its whole length by means of many small adjustable thumb-screws, bearing upon a scraper placed close to the ductor roller; an arrangement which results in giving an almost perfectly uniform supply at each part.

The roll of paper P, supplied to the machine, varies of course in dimensions with the size of the newspaper to be printed. The largest rolls are 7 ft. long and 2 ft. 6 in. diameter, the weight of each roll being about 1300 lbs., and the length 4 miles. Smaller rolls of 5 ft. × 2 ft. 6 in. are also used.

The roll of paper is prepared for the machine the day before, or several days before, by a damping process; in which

it is unwound from its original roll and re-rolled on another, after application of moisture to the extent of about 4 per cent. of its weight. In some printing machines, even for very high speeds, the previous damping process is omitted, and damping arrangements are attached to the printing machine itself; but in this case, owing to the extreme rapidity with which the paper flies through the machine, however evenly the moisture may be supplied, it must, in the writer's opinion, meet the type while yet glistening, so to speak, on the surface of the paper, rather than with the paper mellowed throughout its substance, as it is by an interval of rest after damping. And the saving effected by omitting the separate process of damping is so slight, that it will probably be thought that this disadvantage outweighs it greatly.

The slightly damped roll of paper P, of the dimensions described, Fig. 1, Plate 72, is, in the *Newcastle Daily Chronicle* office, lifted by a hydraulic crane on to two supports above the centre of the printing machine; and a small weighted brake strap S is applied, to prevent overrunning and to give uniformity of tension. The pressure of the brake can be regulated by the attendant at will. The end of the web or ribbon of paper is passed under a guiding roller, is placed between the first type and impression cylinders A_1 and B_1, and is guided from thence to pass between the second type and impression cylinders A_2 and B_2. The machine may now be slowly started; which is done by ordinary fast and loose pulleys and shifting gear, the belt slipping somewhat as it moves from the loose on to the fast pulley, so that the starting is not absolutely sudden. The pull of the paper alone causes the revolution of the paper roll, which of course varies in size every moment; the impression parts of the machine however are accurately geared together, so as to preserve the most exact register. An ingenious apparatus is fixed on the machine for the adjustment of register. The passage between the first type and impression cylinders A_1 and B_1 prints one side of the paper; and the passage between the second type and impression cylinders A_2 and B_2 (the other side of the paper being now turned to the type) prints the reverse side. The second type cylinder A_2 is of exactly the same size as the first; but the second impression cylinder B_2 is made three times the size of the first, and

runs at one-third the number of revolutions. The reason for this arrangement, which is one of the peculiarities of the Hoe machine, is as follows. The newly printed surface of the first side of the paper comes in contact with the blanket of the second impression cylinder, while the second side is being printed; and the ink being perfectly fresh and slightly wet, a small portion of it adheres to the blanket. The continual succession of sheets by degrees accumulates so much ink on this second blanket that it begins to part with some of it to the paper, so as to disfigure it; and the blanket must then be reversed or changed. If the impression cylinder were the same size as the type cylinder, the printing of about 50,000 copies would necessitate a change of blanket and a consequent loss of precious time. Therefore, to diminish this "set-off," as it is called, the diameter is increased three times; and thus, with the aid of some drying on the blanket itself, as many as 250,000 copies can be printed without change of blanket.

When the paper is thus printed on both sides, the still continuous web passes between a third pair of cylinders E E, of equal diameter with the type cylinders; this third pair of cylinders is employed to divide the separate papers transversely from the continuous web. A very ingenious arrangement here comes into play. One of the cylinders is provided with a fixed serrated knife F, and a pair of slightly projecting slips of wood running its whole length. These slips of wood are pressed outwards by means of springs behind them; so that, as these come round, the paper is caught and held for a fraction of a second (although not arrested in its course), by these strips bearing against the other cylinder. At the same moment the serrated knife, which had been as it were ensheathed between the slips of wood, passes through part of the paper held between the two grips described, into a narrow groove in the other cylinder; and thus, without straining the web, the knife nearly but not quite severs the paper in the direction of its width. The web of paper is still continuous, by reason of several small unsevered intervals, but it is so weakened that a slight pull will complete the severance. The continuity is however preserved for a brief interval of time, and the paper is led into an arrangement of lightly touching tapes, intended to convey it into its next position.

This next position is on a combined gathering and folding cylinder G, of larger diameter than the impression cylinder, but running at an equal number of revolutions, and therefore at a higher surface speed. The tapes leading to this cylinder have the same accelerated speed. The consequence of this arrangement is that, when the forward edge of the web of paper is pressed between the cylinder and the tapes, a strain due to the accelerated speed is applied, and the severance of the separate sheets at the nearly severed part is completed: while in addition a regulated space of a few inches, representing the difference in circumference between this gathering cylinder and the type cylinder, is left at the end of each sheet. In this space the grippers of the gathering cylinder have room to operate.

The rate at which the newspapers are delivered, upwards of five per second, is too great to allow each singly to be deposited on a board by reciprocating fliers; and therefore if it be desired to deposit the sheets open, that is to say unfolded, they are first gathered on the combined gathering and folding cylinder G; which is also a peculiarity of the Hoe machine. If this cylinder be arranged to act as a gathering cylinder only, Fig. 1, Plate 72, it receives and retains a sheet at each revolution, until 5, 6, 7, or any predetermined number, are collected upon it, one above the other. The accumulation being complete, the points of a series of switches H are quickly rocked into grooves on the cylinder G, just as the space between the ends of the sheets, before referred to, is passing in front of them; they thus run beneath the sheets, and direct them off in a body to the fliers K, which deposit them on a table L. If two copies are printed side by side, as is usually done, a longitudinal cutting arrangement is also required. This consists of a circular cutter M revolving in a closely fitting recess of the cutting cylinder beneath it, while the web of paper passes between the two.

If the papers are to be deposited folded, a separate folding machine, Figs. 2 and 3, Plate 73, is attached to the frame of the printing machine; the gathering arrangement of the combined gathering and folding cylinder G is thrown out of gear, and the folding arrangements are set in action: and the combined cylinder G becomes the first piece of mechanism of the folding machine.

The folding arrangements of this cylinder consist of a flat double-edged revolving folding-blade K, Figs. 4 to 6, which rotates intermittently in its own bearings, near the surface of the cylinder. This blade when at rest lies flat with the periphery of the cylinder G, Figs. 4 and 6, and forms as it were a continuation of it. Its position in the cylinder is nearly opposite to that of the grippers J, so that the centre of a sheet of which the edge is held by the grippers will overlie the leading edge of the folding blade K. In the folding machine, close to the gathering cylinder G, a pair of folding rollers R are located; and, as the gathering cylinder revolves with a sheet upon it, and the folding blade comes round to these rollers, Figs. 4 and 5, the blade is caused by the action of a guiding cam to make a rapid semi-revolution in the opposite direction to the motion of the cylinder. The position and shape of the cam are such that the leading edge of the blade, in rotating and while protruding from the cylinder, describes approximately a hypocycloidal curve, the effect of which is that the blade inserts the centre of the sheet neatly between the folding rollers R, and then itself withdraws again. At the same instant the grippers J release the forward edge of the sheet, and it is drawn backwards, while the rear end is drawn forwards, by the folding rollers; and thus the first fold is given, Fig. 6, and the gathering cylinder G becomes so far clear for another paper. The folding rollers R are set up against each other, and held in that position, by springs, so as to introduce some elasticity in the hold upon the paper. When the beginning of the doubled paper passes out of the first folding rollers R, it meets with a switch arrangement S, Fig. 2, which diverts every alternate paper upwards or downwards into a position whence it is carried by one or other of two series of tapes to two second pairs of folding rollers R_1 and R_2, with reciprocating blades. From these it takes its second fold, at right angles to the first, and finally passes into new guiding tapes, so timed and so arranged that two folded papers are laid down together by each of four sets of reciprocating fliers M, Fig. 3, on one of four tables N; each movement of a flier thus representing the completion of eight papers.

There is a counting arrangement attached, by which not only

can the number of papers printed be registered, but they are even delivered automatically in counted parcels or quires. When the papers have been delivered by the machines, they are conveyed by boys to the despatch-room hoists, and are there rolled in definite numbers and secured in previously addressed wrappers; to be finally despatched to various trains, or in conveyances, as required.

The production of a machine, such as described, is about 20,000 perfected copies per hour. The *Newcastle Daily Chronicle* Office is arranged for five such machines, although only one has yet been erected.

The *Chronicle* Office contains a variety of hydraulic machinery supplied by Sir W. G. Armstrong & Co., and comprising three hydraulic lifts, two hydraulic cranes, and one hydraulic hoist. Thus the paper need never be lifted by hand until it is ready for the despatch department, where it is usually divided into such parcels as may be conveniently handled. The cranes are arranged to supply paper to two machines, and there are two lifts to supply the despatch department, so that one can be filled and the other emptied simultaneously. The cranes and hoists are arranged to run their chains out without the usual counterweight, so that only the weight of the hook and part of the chain need be dealt with in hooking on or off. The working of the hydraulic machinery is all that can be desired. Extraordinary precautions of various kinds are adopted in the way of duplicate appliances, in case it should be necessary to effect repair or alteration to any part. Any one of three boilers, for instance, can be used for either of four separate large engines, each of which can be made to work either of two lines of shafting, and so on.

Amongst the advantages pertaining to the use of the printing machine here described may be mentioned;—first, its enormous production; next, that the web perfecting machine, as compared with the old form of rotary machine (which will also be seen in operation), saves not only time, but also a considerable percentage of wasted paper, due to the imperfections of hand-feeding; next, that it is suitable at once for the largest size of newspaper printed and also for

various smaller sizes (the folding machine being made telescopic, so as to suit differences of size); next, that it is remarkable for the clearness of its impression; and lastly, that, owing to its steadiness and uniformity of pull, the lightest paper may be employed.

In conclusion, the writer has pleasure in recording his thanks to Messrs. Hoe and Co. for their great courtesy and kindness in furnishing him with drawings, and explaining many details which he would otherwise have found it very difficult to put before the meeting. Still more does he feel it to be a pleasure and duty to express his thanks to the proprietors of the *Newcastle Chronicle*, and to Mr. R. B. Reed in particular, for assistance afforded in compiling and illustrating this paper.

Discussion on Printing Machinery.

Mr. A. L. Steavenson said it would be interesting to know how wood-cuts were introduced in similar cases. He saw present the representatives of several engineering papers which were illustrated in an admirable manner, and perhaps they would explain how wood-cuts were introduced.

The President asked if wood-cuts could be introduced with the type, so as to give a papier-maché impression.

Mr. Jameson said there were no wood-cuts used in the *Newcastle Chronicle*. They could be introduced with the type so as to give a papier-maché impression; but this could be done only to a limited extent, and not very accurately.

Mr. P. F. Nursey said illustrated papers as a rule were not printed on rotary machines; and consequently the wood-cuts were inserted in the flat formes. Instances sometimes occurred in which wood-cuts were used in the daily papers printed from rotary machines, as was the case occasionally in the *Times*.

Mr. H. S. Hele Shaw observed that the blanket on the second impression roller B_2, Plate 72, did not appear to be continuous. Were the smaller rollers, there shown within the large roller B_2, an arrangement for changing the surface of the blanket without taking it off the larger one?

Mr. Jameson said the object of putting the blanket on the roller in the way arranged was to ensure its tightness, and was merely for the facility of placing it on the roller. It was not changed by rolling round one part or another; but was simply taken off bodily when dirty.

The President did not know whether he ought not to say a few words on the paper, his father having been the first to make a successful printing machine for printing newspapers or books. On p. 517 of the paper a description was given of the mode of distributing the ink, and he could hardly avoid referring to it, because it was as complete a description of the original process introduced in 1818 as it was possible to give. Indeed there was at present no other mode of distributing the ink perfectly than by the end motion of the inking rollers, combined with their revolution. The distributing rollers were compelled to move endways, either by a waving frame, as in the first machines made by his father, or by putting a diagonal roller upon the inking table when the forme was flat: the ink requiring distribution not only lengthways but sideways. It was evident on looking at an ordinary book that if the ink were taken off the roller over the type, but not over the margin, it must accumulate on the roller over the margin, unless it was distributed. By the end motion across the type, there was a perfect distribution of ink over the whole surface. That was carried out in practice in every printing machine in one way or another.

The arrangement of the machine described appeared to be extremely complete. One point was especially worthy of notice—the power of working different widths of paper, going up to 7 ft. He did not know whether with narrower sheets it was found necessary to put overlaying, on account of the cylinders springing.

He presumed that the 5 ft. width would be printed in the middle of the length of 7 ft.; otherwise he should imagine that there might be an unequal spring of the roller. He agreed with the author in what he said about damping the paper. It was much better to have the paper in a mellow condition than in the condition in which it was sometimes put through, with a slight shower on the surface, and without being thoroughly damped. The speed of printing —20,000 copies an hour—was very high, and he believed it was about as fast as anything that had been done. At the time his father invented the first printing machine he used a rotary machine, but long sheets of paper were not then to be had: and there was another thing which was at the root of the whole matter, as had been truly stated, namely the casting of stereotype plates. It was a fact not commonly known that a Frenchman named Pomba made paper moulds about 1830, as much like those exhibited as possible; but he did not hit upon the plan of putting the papier-maché mould into a cylinder and running the metal against it, so as to cast a curved stereotype plate. It was only intended to make flat plates. By his father's process the plates were made flat and then bent. That plan was good, though not quite perfect, and a considerable amount of printing had been done in that way. All Day & Martin's blacking labels had been printed in red and black in register, from curved stereotype plates; they were cast flat first, and then curved by means of rollers. But the new mode of casting plates in the form of a cylinder was as near perfection as anything could be; he believed it was the invention of M. Delagoué. It involved an interval of only 20 or 25 minutes between the arrival of the type in the stereotype room and the supply of the stereotype plates to the printing room; and he believed that in the *Times* office, under the excellent management of Mr. Macdonald, it had been done, and ten copies printed, in 19½ minutes, or in 20 minutes frequently. He thought they ought to thank Mr. Jameson heartily for his paper— one of the first they had had upon printing machinery.

Mr. Jameson said it was only necessary for him to answer one question, with regard to the spring of the impression cylinder,

Plate 72. The second impression cylinder B_2 was of course very strong, and this supported the first cylinder B_1, so that they were both perfectly steady: there was also a subsidiary inking roller X above each of the type cylinders A_1 A_2, and by means of this all shake was taken off, so that no overlaying was required in printing 7 ft. or 5 ft. sheets. They were printed in the centre of the roller length, without spring of any consequence being occasioned.

ON SOME RECENT IMPROVEMENTS IN LEAD PROCESSES.

By Mr. NORMAN C. COOKSON, of Newcastle.

In few trades have a smaller number of changes been made, during recent years, in the processes employed, than in that of Lead Smelting and Manufacturing.

In the North of England we find the old Scotch ore hearth and the slag hearth still in operation, and by the former the bulk of our local ores are smelted.

In the next stage of manufacture—desilverizing—we find the "Pattinson process" worked substantially in the same way as when originally introduced by the late Mr. Hugh Lee Pattinson, in the year 1833; in some cases with a few improvements, but generally unchanged. By this process, locally termed "separating," most of the silver lead is operated on; but of late years two other processes, presently to be described, have been largely worked on the Tyne.

In sheet lead rolling, there is no alteration in principle since the time when the first mill took the place of the old casting-floors, some centuries ago. But in a mill put up a few years since by the writer's firm many very important improvements in detail were introduced.

In pipe manufacturing, the only change is from pipe-drawing to pipe-pressing, by means of the hydraulic press; and in the modern pipe press solid cores are now used, almost to the exclusion of the old-fashioned split cores.

In shot making, since the time when Messrs. Walkers Parker and Co. put up their first shot-tower, and when, very shortly afterwards, Messrs. Locke Blackett and Co., to avoid the expense of a tower, substituted a disused pit shaft, no changes have taken place.

An ingenious American has however patented a process for using a short shaft, some 8 or 10 ft. in height, through which as the molten shot-drops fall they meet a strong current of air, urged by a fan, which answers the purpose of the long drop in a tower or pit.

In the manufacture of white lead, the old "Dutch process," the same as has been used for many centuries, produces in this country at least nine-tenths of all that is made, and of a quality not yet surpassed, if equalled. As to red lead making, neither in the old ovens nor in the mode of working them has there been any alteration.

The object of this paper however being to describe, not what is unchanged, but some recent improvements in lead processes, the writer will briefly notice a few, and those more especially with which he is best acquainted, namely those applied to desilverizing and sheet-lead rolling.

Before describing desilverizing by the "steam process," as it is worked by the writer's firm, it will be well to give a short description of the "Pattinson process," inasmuch as in principle the two are almost identical. The Pattinson separating process is based on the fact that, when melted silver lead cools, the crystals first forming contain less silver than the portion which remains longest liquid; and in practice it is worked as follows. A set of about ten or a dozen cast-iron pots, holding from five to fifteen tons each, are placed in a row, each over a fire. Of these the last towards one side, or the market pot, is generally smaller than the others. Should the lead to be worked contain, say, 25 ounces of silver per ton of lead, it will probably be filled into the middle pot of the series. It will then be melted; and when the whole is thoroughly liquid, the fire will be drawn, and the lead allowed to cool. As it cools, a workman keeps stirring the lead, and slicing, or freeing from the sides, the portions setting on them. As the cooling proceeds, crystals begin to form; and when a sufficient quantity appear, a second workman withdraws the crystals from this pot with a perforated iron ladle, and passes them into the pot to his right, towards the market pot, and continues doing so until he has thus moved two-thirds of the

lead. When he has done this, he withdraws with a solid-bottomed ladle the one-third of liquid lead remaining, and moves it to the pot on his left. The centre pot is again filled with original silver lead, and the same operation is repeated. If this has been properly conducted, it will be found that the liquid lead removed to the left, instead of containing 25 ounces of silver per ton, as did the original lead, will now contain 50 ounces per ton; and the crystals moved towards the market pot will contain $12\frac{1}{2}$ ounces per ton. It will readily be seen that, by repeating this operation successively in the various pots, the poor lead gradually becomes poorer, until it is so free from silver as no longer to pay for working; while the rich lead, on the other hand, will gradually increase in richness, till its proportion of silver makes it fit for the refinery.

Although other processes for desilverizing are extensively worked, this original "Pattinson process" is still that which is most largely used in England.

The "steam desilverizing process," as used in the works of the writer's firm, and in other works licensed by them, is the invention of Messrs. Luce Fils et Rozan, of Marseilles: it is one which should commend itself especially to engineers, as in it mechanical means are employed, instead of the large amount of hand-labour used in the Pattinson process. The steam desilverizing process, instead of a row of pots, as in the old process, employs two melting pots only; of which the lower or working pot W, Figs. 1 and 2, Plate 74, is placed at such a height that the bottom of it is about 12 to 15 in. above the floor level, while the upper or melting pot M is placed at a sufficiently high level to enable the lead to be run out of it into the lower pot. The capacity of the lower pot, which in those most recently erected is 36 tons, should be not less than double that of the upper one. Round each pot is placed a platform GG, on which the workmen, of whom there are two only to each apparatus, stand while charging, slicing, and skimming the pots. The upper pot is open at the top, but the lower one has a cover, with hinged doors LL; and from the top of the cover a funnel is carried to a set of condensers. At a convenient distance from the two pots is placed a steam or hydraulic crane, so arranged that it

can plumb each pot, and also two large moulds BB which are placed at either side of the lower pot.

The mode of working is as follows. The silver lead is charged into the upper or melting pot M, Plate 74, by means of the crane. When melted, the dross is removed, and the lead run into the lower or working pot W, among the crystals remaining from a previous operation. When the whole charge is thoroughly melted, it is again drossed; and in order to keep the lead in a thoroughly uniform condition, and prevent it from setting solid at the top and round the outside, a jet of steam is introduced from the pipe P. To enable this steam to rise regularly in the working pot W, a disc-plate D is placed above the nozzle, which acts as a baffle-plate; and uniform distribution of the steam is the result. To quicken the formation of crystals, and thus hasten the operation, small jets of water are allowed to play on the surface of the lead. This, it might be thought, would make the lead set hard at the surface; but the violent action of the steam works in the most effectual manner in causing the regular formation of crystals. Owing to the ebullition caused by this action of the steam, small quantities of lead are thrown up, and set on the upper edges and cover of the pot. From time to time the valve controlling the thin streams of water playing on the top of the charge is closed, and the workman, opening the doors of the cover in rotation, breaks off this solidified lead, which falls among the rest of the charge, and instantly becomes uniformly mixed with it. Very little practice enables an ordinary workman to judge when two-thirds of the contents of the working pot W are in crystals, and one-third liquid; and when he sees this to be the case, instead of ladling out the crystals ladleful by ladleful, as in the old Pattinson process, he taps out the liquid lead by means of two spouts SS, controlled by valves, the crystals being retained in the pot by means of perforated plates. The liquid lead is run into large cone-shaped moulds BB on either side of the pot; and a wrought-iron ring being cast into the blocks thus formed, they are readily lifted, when set, by the crane. To give some idea of the rapidity of the process, it may be mentioned that, from the time the lead is melted and fit to work in the big pot, to the time that it is crystallized and ready for tapping, is in the case of a 36-ton pot from thirty-five to forty-

five minutes; and the time required for tapping the liquid lead into the large moulds is about eight minutes. Before the lead begins to crystallize, the upper pot is charged with lead of half the richness of that in the lower pot. Thus, when the liquid lead has been tapped out of the lower pot, it is replaced by a similar amount of lead of the same richness as the remaining crystals, by simply tapping the upper or melting pot, and allowing the contents to run among the crystals. The same operation is repeated from time to time, until the crystals have become so poor in silver that they are fit to be melted down, and run into pigs for market.

The large blocks of partially worked lead are placed by the crane in a semicircle round it, and pass successively through the subsequent operations, as follows. In usual working there are kept on hand 12 tons weight of blocks of each of the several qualities of lead, which are numbered for convenience from No. 1 to No. 12, and contain the following quantities of silver per ton:—

Quality or No. of lead	1	2	3	4	5	6	7	8	9	10	11	12
Ounces of silver per ton of lead	640	320	160	80	40	20	10	5	$2\frac{1}{2}$	$1\frac{1}{4}$	$\frac{5}{8}$	$\frac{5}{16}$

Should the lead as received from the smelting works contain 40 oz. of silver per ton, it would go into the furnace as No. 5; and the result of working the 36-ton charge would be 12 tons of No. 4 tapped out into blocks, and 24 tons of No. 6 remaining in the working pot as crystals. The working pot would then be filled up to 36 tons by adding 12 tons of No. 6 blocks; and when this charge was worked, the result would be 12 tons of No. 5 tapped out into blocks, and 24 tons of No. 7 remaining in the pot as crystals. It will be seen that by working thus each set of blocks is moved forwards one stage at each working. When it comes to the turn of No. 12, the resulting crystals are market lead, which simply require to be melted and run into pigs or blocks, as may be desired.

This process has other great advantages in addition to that of saving labour. In the first place, after taking into account the fuel used for supplying the crane power, and the steam for crystallizing, it still shows a great economy in fuel. In the case of the writer's

firm, they find that, in comparison with the Pattinson process, as formerly carried out by them, only one-third of the amount of coal is used, though of a slightly better quality. Another most important advantage is that the steam, in addition to its mechanical effect, produces an effect of a chemical nature. Almost all silver leads, as received, contain impurities, such as copper, arsenic, iron, and antimony. In the Pattinson process these extraneous metals had to be removed by calcination, before the lead could be used in the separating department. But it is found that in the Rozan or steam process these extraneous metals, if they exist in moderate quantities (as is usually the case in English, Spanish, and other leads of similar quality), are readily oxidised by the steam; and that their presence in the desilverizing apparatus, instead of being a disadvantage, is a positive advantage, since, where a small quantity of antimony or copper exists, its presence has the effect of lessening the oxidisation of the lead. A small quantity of oxide of lead and other oxides is carried off mechanically from the lower pot by the steam and by other gases, which escape from thence after having done their work; but they are conducted by the funnel on the top of the pot cover to condensers, where the metals are practically all recovered. These oxides are found to contain a very large quantity of antimony and copper, and in colour are nearly black, instead of the yellow proper to pure lead oxide.

To sum up, the advantages of the steam process, as compared to the old 6-ton Pattinson pots formerly used by the writer's firm, are:—(1) a saving of two-thirds in the amount of fuel used; (2) the saving of the cost of calcining the lead, to the extent of at least four-fifths of all the lead used; (3) above all a saving in labour to the extent of two-thirds. The process has its disadvantages, and these are a larger original outlay for plant, and a constant expense in renewals and repairs. This is principally caused by the breakage of pots; but with increased experience this item has been very much reduced during the last two or three years.

The third method of desilverizing worked in this district is the "zinc process," which is largely used by Messrs. Locke Blackett and Co., and was patented in the form adopted by them about fourteen years since. The action of this process is dependent on the

affinity of zinc for silver; the following is a brief description of it. A charge of silver lead, usually about fifteen tons, is heated to a point considerably above that which is used in either the Pattinson or the steam process. The quantity of zinc added is regulated by the amount of silver contained in the lead; but for lead containing 50 oz. to the ton, the quantity of zinc used is in most cases about $1\frac{1}{2}$ per cent. of the charge of lead. The lead being melted as described, a portion of this zinc, usually about $\frac{3}{4}$ per cent., or half of the total quantity required for the charge, is added to the melted lead, and thoroughly mixed with it by continued stirring. The lead is now allowed to cool, when the zinc is seen gradually to rise to the top, having incorporated with it a large proportion of the silver. The setting point of zinc being above that of lead, a zinc crust is gradually formed, and this is broken up and carefully lifted off into a small pot conveniently placed, care being taken to let as much lead drain off as possible. The fire is again applied strongly to the pot, and when the lead is sufficiently heated, a further quantity of zinc, about $\frac{1}{2}$ per cent., or one-third of the whole quantity used, is added, when the same process of cooling and removing the zinc crust is repeated. This operation is gone through a third time, with the remaining portion ($\frac{1}{4}$ per cent.) of zinc; and if each of these operations has been carefully carried out, the lead will be found to be completely desilverized, and will only show a very small trace of zinc. In some works this trace of zinc is allowed to remain in the market lead, but at Messrs. Locke Blackett and Co.'s works it is invariably removed, by subjecting the lead to a high heat in a calcining furnace. The zinc crusts, rich in silver, are freed as far as possible from the lead by allowing this to sweat out in the small pot, after which the crusts are placed in a covered crucible, where the zinc is distilled off, and a portion of it recovered. The lead remaining, which is extremely rich in silver, is then taken to the refinery, and treated in the usual manner. The writer is given to understand that the quantity of zinc recovered is as high as from 50 to 60 per cent. of the total quantity used.

This process has much to recommend it in the small original cost of plant, the small amount of labour, and the extreme quickness with which the lead can be treated. The stock of working lead

required is also small, as compared with either the Pattinson or the steam process. Against this however is to be set the cost of the zinc which is lost; and when the writer watched the working of the process carefully some years since, the results in silver and lead were not so satisfactory as he had expected.

Although it was said that the rolling or milling of lead remains unchanged in its main features since the first mill was established, yet the writer's firm have introduced many important improvements. Of one of these the advantage is perhaps felt more in the desilverizing than in the rolling department; and in the following way. When lead is required for sheet making, instead of running out the market lead into the usual pigs of about one hundredweight each, it is run into large blocks of 3½ tons; and by so doing a very great saving both of time and labour is attained. These 3½-ton blocks are taken on a bogie to the mill-house, where the mill melting-pot is charged with them by means of a double-powered hydraulic crane, lifting however with the single power only. Three such blocks fill the pot, and when melted are tapped out on to a large casting plate, forming a slab 8 ft. 4 in. by 7 ft. 6 in., and about 7 in. thick. This slab, weighing 10½ tons, is lifted on to the mill table by the same crane that fills the pot, but using the double power; and is moved along to the rolls in the usual manner by means of a rope working on a surging head. The mill itself, as regards the rolls, is much the same as those of other firms; but instead of an engine with a heavy fly-wheel, always working in one direction, and connected to the rolls by double clutch and gearing, the work is done by a pair of horizontal reversing engines; in connection with which there is a very simple, and at the same time extremely effective, system of hydraulic reversing. In other lead mills there is no necessity for fine or delicate control of the engines; but with this system it is essential, and the hydraulic reversing gear contributes largely to such control. This may be explained as follows. In all other mills with which the writer is acquainted, when the lead sheet, or the original slab, has passed through the rolls, and before it can be sent back in the opposite direction, a man on either side of the mill

must work it into the grip of the rolls with crowbars. In the writer's system this labour is avoided, and the sheet or slab is fed in automatically by means of subsidiary rolls, which are driven by power. When it is required to cut the slab or sheet by the guillotine, or cross-cutting knife, instead of the slab being moved to the desired point by hand-labour, the subsidiary driven rolls work it up to the knife; and such perfect control does the engine, with its hydraulic reversing gear, possess, that should the sheet over-shoot the knife $\frac{1}{8}$ in., or even less, the engine would bring it back to this extent exactly.

Another point, which the writer looks upon as one of the greatest improvements in this mill, is its being furnished with circular knives, which can be set to any desired width, and put in or out of gear at will; and which are used for dressing up the finished sheet in the longitudinal direction. This is a simple mechanical arrangement, but one which is found to be of immense benefit, and, in the writer's opinion, is far superior to the usual practice of marking off the sheet with a chalk line, and then dressing off with hand knives. The last length of the mill table forms a weigh bridge, and a hydraulic crane lifts the sheets from it, either on to the warehouse floor, or the tramway communicating with the shipping quay.

Though the description of the "steam desilverizing" process, and of sheet lead rolling, which the writer has endeavoured to give, may not perhaps have been as clear and interesting as he would have wished, he feels sure that those members who visit the works, and see the processes in operation, will be able to follow them through with facility, and will find their details of considerable interest. It will afford him much pleasure to explain on the spot any other matters here omitted for the sake of brevity.

Discussion on Lead Processes.

Mr. HUGH LEE PATTINSON said that Mr. Cookson and others on the Tyne had carried out his father's process for many years; and they were more competent to speak upon the details of it than himself. He had nothing to say with regard to Mr. Cookson's paper, except that it exactly described the principle of his father's process. He had been much interested in listening to the account of the improvements which Mr. Cookson's firm had carried out.

The PRESIDENT said the paper was a very interesting one, giving a clear insight into the process, so that the members would be able to understand the apparatus when they saw it at work that afternoon at Messrs. Cookson's. He had that morning seen the Rozan process in operation at Messrs. Walker's works. He had seen the blowing of the steam into the liquid lead, and the agitation in the pot was wonderful—something that one would not dare to do off hand; but he supposed it had been gradually arrived at. There were waves of lead 6 in. high, and a splashing 18 in. high. There was a cover to keep the lead from flying about, and water was thrown on in *thin streams;* but before the workmen opened the lid of the pot they turned off the water; still the splashing from the steam continued, and the workmen then scraped the lead off the lid, and threw it back into the pot. He had also seen one of the vessels being tapped, and the lead run out into a large pan, with a piece of iron in the middle, forming an eye to lift it up by.

Mr. W. E. RICH said there was one point in connection with the manufacture of lead, which he had accidentally noticed, and which no doubt was known to many gentlemen present, but not perhaps to all, namely the extremely low specific heat and latent heat of lead. Its specific heat was only 0·03, or about $\frac{1}{30}$ that of water; and its latent heat of liquefaction was also so low (about 10 units), that it took about five times as much heat to melt 1 lb. of ice at

32° Fahr. as to warm up and melt 1 lb. of lead also at 32°. That no doubt accounted for the freedom with which the manufacturers of lead seemed to let it cool and then heat it up again to the melting point—a treatment which would be very wasteful of fuel in most other metallurgical processes.

Mr. Cookson said he could corroborate from practice the remark just made by Mr. Rich. He had roughly reckoned up the weight of lead, principally in the state of crystals, that was reduced to liquefaction by 1 ton of coal. Taking the ordinary consumption of coal in regular working, he found that by 1 ton of coal upwards of 300 tons of lead were brought up from the crystallising point—or from slightly below that, for the lead was partially solid and partially in crystals—to the melting point.

The President asked if Mr. Cookson could say whether the Pattinson or the Rozan process made softer and more pure lead.

Mr. Cookson replied decidedly the Rozan process; and he thought he could prove it. By the old Pattinson process a considerable number of leads, such as Greek lead, containing a great amount of impurities, could be used only for making into common lead, sheet lead, &c., as white lead required a much better quality. By the Rozan process even Greek leads could be made thoroughly fit for white lead or glass-makers' red lead, or for any purpose that required the very purest quality. The Pattinson process would not enable that to be done, at any rate not without putting more cost on the process than would pay commercially.

ON A FEED-WATER HEATER AND FILTER FOR STATIONARY AND LOCOMOTIVE BOILERS.

By Mr. GEORGE S. STRONG, of Philadelphia, U.S.

In most feed-water heaters the purification of the water from matter held both in solution and suspension is to a great extent an accidental circumstance, not contemplated in their design. Where soft waters are in use special attention need not be given to this point, but where hard water prevails too much attention cannot possibly be paid to it.

Many devices have been used to purify the water before entering the boiler. Some seek to precipitate the dissolved salts by chemical means, such as the addition of carbonate of soda or carbonate of lime, and then either allow the water to settle or pass it through a filter. It is unnecessary to urge the inconvenience of any chemical method; the drawbacks are only too apparent.

In designing the feed-water heater now to be described, the writer paid special attention to the separation of all matters, soluble and insoluble; and he has succeeded in passing the water to the boilers perfectly pure, and free from any substance which would cause scaling or coherent deposit. His attention was more particularly called to the necessity of extreme care in this respect, through the great annoyance suffered by steam users in the central and western parts of the United States, where the water is heavily charged with lime. Very simple and even primitive boilers are there used; the most necessary consideration being handiness in cleaning, and not the highest evaporative efficiency. These boilers are therefore very

wasteful, only evaporating, when covered with lime scale, from two to three pounds of water with one pound of the best coal, and requiring cleaning once a week at the very least. The writer's interest being powerfully aroused, he determined if possible to remedy these inconveniences; and accordingly he made a careful study of the subject, and examined all the heaters then in the market. He found them all, without exception, insufficient to free the feed water from the most dangerous of impurities, namely the sulphate and the carbonate of lime.

That this assertion is correct may be proved by the following quotation from the guarantee given by the Berryman Heater Company:—"I guarantee every heater to deliver the feed water to the boilers at a uniform temperature of 200° Fahr. and above, using exhaust steam, and also to free said water from all impurities (with the exception of salt, sulphate of lime, and such other acids as cannot be separated except by evaporation), and that its use will not in any way interfere with the use of the exhaust steam for heating purposes, and I invite orders subject to such guarantee."

Carbonate of lime is almost insoluble in pure water, but it is soluble to a great extent in water containing carbonic acid gas in solution. Thus dissolved, it gives rise to what chemists call in their analysis reports "temporary hardness." This temporary hardness disappears when the water is boiled, because the carbonic acid gas is expelled in boiling, and the carbonate of lime is precipitated; causing the water to become milky in appearance, from the finely powdered chalk suspended in it.

"Permanent hardness" arises from the presence of sulphate of lime, or sulphate of magnesia. At the ordinary temperature of boiling water, and at atmospheric pressure, a portion of the sulphate of lime is deposited, though from a cause quite different from that of the precipitation of the carbonate. It has been found that sulphate of lime is much more soluble in cold water than in hot, which is a reversal of the usual order of things with soluble salts; and accordingly water containing this substance may be quite freed from it by heating to a sufficiently high temperature.

The following Table shows the solubility of sulphate of lime in water at different temperatures :—

TABLE I.

Temperature Fahr.	Sulphate of Lime. Percentage held in Solution.
217°	0·500
219°	0·477
221°	0·432
227°	0·395
232°	0·355
236°	0·310
240°	0·267
245°	0·226
250°	0·183
255°	0·140
261°	0·097
266°	0·060
271°	0·023
290°	0·000

The reason of sulphate of lime becoming insoluble on heating seems to be the gradual decomposition of the hydrate. Anhydrous calcic sulphate is insoluble in water, but if it be hydrated it then dissolves; hence, by causing the water to attain a sufficiently high temperature, the dehydration is effected and the anhydrous sulphate is deposited.

Sulphate of magnesia, the remaining impurity which commonly occurs in water, does not precipitate on boiling or heating the water. Carbonate of magnesia behaves in the same way as carbonate of lime, coming down as soon as the carbonic acid is expelled.

Taking these facts, well known to all chemists, as the basis of his operations, the writer perceived that all substances likely to give trouble by deposition would come down at a temperature of about 250° F.

His plan was therefore to make a feed-water heater in which the water could be raised to that temperature before entering the boiler. Now by using the heat from the exhaust steam, the water may be raised to between 208° and 212° F. It has yet to be raised to 250° F.; and for this purpose the writer saw at once the advantage that would

be attained by using a coil of live steam from the boiler. This device does not cause any loss of steam, except the small loss due to radiation, since the water in any case would have to be heated up to the temperature of the steam on entering the boiler. By adopting this method, the chemical precipitation, which would otherwise occur in the boiler, takes place in the heater; and it is only necessary now to provide a filter, which shall prevent anything passing that can possibly cause scale.

The heater, being subject only to a strictly determinate temperature, does not cause the precipitate to adhere to the tubes or metal, so that scale cannot be formed in it; since, to produce sufficient coherence to form scale, it is necessary that the metal should be heated considerably above the temperature of the water, in fact that the flame of the fire should play on one side of it.

Having explained as shortly as is possible the principles on which the system is founded, the writer will now describe the details of the heater itself.

In Figs. 1 to 3, Plate 75, are shown an elevation, a vertical section, and a sectional plan of the heater. The cast-iron base A is divided into two parts by the diaphragm B. The exhaust steam enters at C, passes up the larger tubes D, which are fastened into the upper shell of the casting, returns by the smaller tubes E, which are inside the others, and passes away by the passage F. An enlarged section of the upper part of the tubes is shown in Fig. 4, in which the course of the exhaust steam is shown by the arrows. The inner tube only serves for discharge. It will be seen at once that this arrangement, while securing great heating surface in a small space, at the same time leaves perfect freedom for expansion and contraction, without producing the slightest strains. The free area for passage of steam is arranged to be one-and-a-half times that of the exhaust pipe, so that there is no possible danger of back pressure. The malleable iron shell G, connecting the stand A with the dome H, is made strong enough to withstand the full boiler pressure. An ordinary casing J, of wood or other material, prevents loss by radiation of heat. The cold water from the pump passes into the

heater through the injector arrangement K, and coming in contact with the tubes D is heated; it then rises to the coil L, which is supplied with steam from the boiler, and thus becomes further heated, attaining there a temperature of from 250° to 270° F., according to the pressure in the boiler. This high temperature causes the separation of the dissolved salts; and on the way to the boiler the water passes through the filter M, becoming thereby freed from all precipitated matter, before passing away to the boiler at N. The purpose of the injector K, and the pipe passing from O to K, is to cause a continual passage of air or steam from the upper part of the dome to the lower part of the heater, so that any precipitate carried up in froth may be again returned to the under side of the filter, in order more effectually to separate it, before any chance occurs of its passing into the boiler.

The filter consists of wood charcoal in the lower half, and bone black above, firmly held between two perforated plates, as shown. After the heater has been in use for from three to ten hours, according to the nature of the water used, it is necessary to blow out the heater, in order to clear the filter from deposit. To do this, the cock at R is opened, and the water is discharged by the pressure from the boiler. The steam is allowed to pass through the heater for some little time, in order to clear the filter completely. After this operation all is ready to commence work again. By this means the filter remains fit for use for months, without change of the charcoal.

Where a jet condenser is used, either of two plans may be adopted. One plan takes the feed water from the hot well, and passes the exhaust from the feed pumps through the heater, using at the same time an increased amount of coil for the live steam. By this means a temperature of water is attained, high enough to cause deposition, and at the same time to produce decomposition of the oil brought over from the cylinders. The other plan places the heater in the line of exhaust from the engine to the condenser, also using a larger amount of coil. Both these methods work well. The writer sometimes uses the steam from the coil to work the feed pump; or, if the heater stands high enough, it is only necessary to make a

connection with the boiler, when the water formed by the condensation of the steam runs back to the boiler, and thus the coil is kept constantly at the necessary temperature.

In adapting this system to locomotive boilers, the heater is made in the form of a saddle, to which is bolted a dome containing the coil and filter. A pipe, taken from the bottom of the right-hand blast nozzle, communicates with the exhaust chamber of the heater, and from the discharge side passes again to the same nozzle, where, by the construction of the nozzle, it is passed out to the atmosphere with the main body of steam. By this method no steam is drawn from the blast, except that actually required to heat the water. This steam of course condenses; but care is taken to draw off the water formed, so as not to discharge water at the blast. The amount condensed is 20 per cent. of the whole steam used. It will be observed that by this construction there is perfect freedom for contraction and expansion.

The author may be allowed to mention one or two cases where his purifier has done good service, and indeed has been found quite invaluable. The first of the stationary heaters was constructed in the summer of 1879, and was attached to a battery of boilers at the Eliza Furnace, in Pittsburg, owned by Lauchlin and Co. These boilers deposited scale very fast, so fast that it was necessary to chisel the scale off every fortnight when they were worked during the day, and every week when kept going constantly. After having run with the heater for a fortnight, the boilers were opened, and the scale was found quite loose, and came away quite easily. They were then run one month, and so little scale was formed that it was unnecessary to remove it. They now run six months continuously before requiring any cleaning whatever.

Another heater was fitted to a battery of tubular boilers, using water from New York Bay, or from an adjoining salt marsh. These boilers had constantly burned out from six to ten tubes per week, and it was impossible to clear out the scale. It formed so hard in the tubes that it could not be driven out: it would even stand the steam pressure after the iron was completely burned away, and then would break in two like a pipe-stem. After using the heater

for some weeks, the scale was found to be quite soft, and a plug could be driven right through the tube, carrying the scale before it. These boilers are now worked with very little difficulty.

The writer has now had wide experience with this heater in the United States, using every kind of water, and has obtained good results in all cases: and having recently made arrangements for its manufacture in this country, he doubts not he will be able ere long to point to equally satisfactory results in Europe.

Discussion on Feed-Water Heater and Filter.

The President said Mr. Strong was present, having crossed the Atlantic on purpose to attend the meeting; and the members would be glad to hear any observations from him before the discussion commenced.

Mr. Strong wished to add a word about the process of blowing-off. By opening the cock R and blowing the live steam downwards from the top through the filter, it blew all the water out of the heater, and drove out the sulphate and the carbonate; so that it was not necessary to change the filter very often. At Pittsburg, where the water was very bad, a heater had run for six months without changing the filter or opening the boilers. Formerly it was necessary to open the boilers once every two weeks.

Fig. 5, Plate 75, showed a simpler arrangement of the tubes, which he was now introducing. Instead of having one tube within another, there was a single tube, divided into two parts, nearly up to the top, by a diaphragm shaped like an S in plan, which was sprung into the tube. The end of the diaphragm projected below the tube, and was bent towards the entering steam; and the effect was that the steam passed up one side of the diaphragm, and down the other.

With regard to locomotive practice, the apparatus had not yet been started in this country, but Fig. 6, Plate 76, showed the form that it would take as applied to an engine on the Metropolitan Railway. There were two heaters A, placed one on each side of the locomotive, between the two pairs of driving wheels, and sunk in the tank, but within a sheet-iron casing to prevent their being chilled by the water. They were connected together, and worked either by pump or injector through the pipe B. The heating was done by taking the exhaust pipe C through the heater on its way to the tank, depending on the effect of the blast to keep the heater sufficiently charged with exhaust steam. Another plan was to fit the heater as an extra dome on the top of the boiler, depending entirely on the live steam within the coil to do the heating. The water was taken from the injector at about 150° Fahr., raised to 250° by the live steam, and then passed direct through the filter to the boiler. This arrangement acted very well as a purifier for water, but did not effect any special economy in heat. In every case the heater could be adapted to suit any special conditions. Fig. 7, Plate 77, showed another form of heater and filter adapted to the standard goods engine of the Great Southern and Western Railway of Ireland. One heater was placed on each side, between the leading and central driving wheels. The exhaust steam was led from the smoke-box through the pipe A into the heater and back again, as already described, and as in use on the American locomotives. The water in this instance was fed by an injector through the pipe B, and the water was heated and filtered as already described, and as shown in Fig. 2 for stationary heaters. The two heaters were coupled by a pipe C, passing over the top of the boiler, close to the base of its dome; and the water was fed from this pipe through a T joint into the boiler, in the usual manner of locomotive practice.

Mr. W. Richardson observed that in the discussion on Mr. Marten's paper on Boilers (Proceedings 1870, p. 214) he had explained the method adopted at Messrs. Platt's works at Oldham in filtering feed-water for boilers. Having there to use sewage water continuously, they had great difficulty and trouble with the mud

deposit: they were not much troubled with lime, but the mud dried in the boilers. They then adopted a filter similar to the one shown, only it was in a strong casing with a cavity at the top and bottom, and the space between the two cavities was filled with animal charcoal. When the water was passed through the filter into the boilers, the mud was deposited among the charcoal. Frequently, perhaps twice a day, they reversed the current, in the way that had been explained, by opening the tap at the bottom and letting the boiler pressure drive some of the clean water back through the filter, so as to cleanse it. That plan had been going on for twenty years, and it had had the effect of keeping the mud out of the boilers; but the water was only heated as high as the exhaust steam would heat it—perhaps to 210° Fahr.

Mr. D. Greig had had considerable experience in feed-water heating for portable boilers; and he thought that the extra heating described in the paper appeared to be a cure for the evils which had been felt, and that Mr. Strong was on the right track.

Mr. W. E. Rich desired to call attention to the remark upon p. 543: "The other plan places the heater in the line of exhaust from the engine to the condenser, also using a larger amount of coil." It would perhaps be scarcely necessary to remind the author that so little value was to be attached to the heat in the exhaust pipe of an engine with any pretensions to economical working, that such an arrangement would be almost if not quite valueless in engines using hot-well water for feed. He generally found that the temperature in the exhaust pipe of an engine working well and with high expansion was not more than one could bear with the hand, say something like 125°. The tendency with most English Boiler Insurance Companies was very strongly to deprecate the use of water which had been through the cylinders, and to use fresh cold water for feeding. Of course in such cases the arrangement of a heater in the exhaust pipe would be much more beneficial.

Mr. T. Abbott said, in what little experience he had had as to

the difficulties connected with feed-water, he had found they were greatest where the men working the boilers were the least skilled; consequently it was very important that a feed-water heater should be as simple as possible. The apparatus explained in the paper seemed to be very good in that respect; but so far as he could see from the drawing, there would be considerable difficulty in withdrawing the filter itself from the casing, which would have to be done possibly once in every three or four months. There seemed a good deal of disconnecting to be done, bolts to undo, &c., in order to get the filter out. If that could be easily got over, he had no doubt it would be a great success.

The President said there was one thing in the paper that struck him at once, and he had hoped that some one would have drawn attention to it. It was stated, p. 539, that in the central or western part of the United States the water was heavily charged with lime, and that the quantity of water evaporated was only from 2 to 3 lbs. for every pound of the best coal. That water must certainly be very exceptional, requiring a large amount of filtering apparatus. In this country they generally had better water than that; but in certain cases where there was a large quantity of sulphate of lime, sulphate of magnesia, and carbonate of lime, he imagined that a filter would be very effective. He was in hopes that some information would be given as to experience of its use in this country.

Mr. Jeremiah Head had always understood that the term "temporary hardness" was applied to carbonate of lime, which was precipitated in boiling, as pointed out in the paper; and that the term "permanent hardness" was applied, as the author had put it, to sulphate of lime and sulphate of magnesia, which were not separated from the water on boiling. But the whole principle of the paper seemed to be founded on what was to him a new fact—that all these substances were precipitated by the addition of another 50° of temperature. The principle of the apparatus was entirely dependent on that fact; and he should like to know whether the experiments which had determined that fact had been made by the author himself, or whether

it was admitted and relied upon by the chemists of this and other countries. If so, then it appeared to him that the author's case was pretty well proved. As a piece of mechanical construction, it seemed to him that the heater was extremely ingenious and well contrived; almost all the parts were circular and symmetrical, and he could hardly conceive a better arrangement for accomplishing what the author desired to effect.

Mr. Charles Cochrane said it seemed to him that, generally speaking, with regard to that class of heater, the water produced by the condensation of the steam was unnecessarily allowed to run to waste. It was becoming a matter of greater and greater importance that they should have practically pure water for their boilers; and no better means existed than that of condensing the exhaust steam which came from the engines. He was aware that there was an objection to doing so, namely that the steam brought over with it a certain amount of acids, which certainly did canker and eat the boilers. For nearly twenty years, having experienced that difficulty, his firm had followed the plan of using a very small proportion of caustic soda in the boilers; and they had never been troubled since. They felt it to be a most important point to save every drop of water coming from the engine, and to use it over and over again; and only to use the water supplied from extraneous sources to make up the deficiency arising in the circulation.

Mr. Hugh Lee Pattinson said, in reply to Mr. Head, that it was a well known fact in chemistry that sulphate of lime was rendered insoluble at high temperatures.*

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* The following additional information has since been kindly furnished by Mr. Pattinson. "The solubility of sulphate of lime in water diminishes as the temperature rises. At ordinary temperatures pure water dissolves about 150 grains of sulphate of lime per gallon; but at a temperature of 255° Fahr., at which the pressure of steam is equal to about 2 atmospheres, only about 40 grains per gallon are held in solution. At a pressure of 3 atmospheres, and temperature of 302° Fahr., it is practically insoluble. The point of maximum solubility is about 95° Fahr. The presence of magnesium chloride or of calcium chloride in

Mr. STRONG said that, by means of this heater, with a vacuum of 26 in. of mercury in the condenser, he got a temperature of about 135° Fahr. in the heater from the exhaust, and about 150° with a vacuum of 22 in. Thus by using the exhaust steam to heat the cold feed-water he gained the difference between say 60° and 140°, which was worth something like 4 or 5 per cent. of the fuel used. Again, if he took the water from the hot-well, at a temperature of from 90° to 100°, he still got a further 40° of increased temperature by using the condensed steam, which was worth something like $2\frac{1}{2}$ or 3 per cent. of the fuel. At the same time, by passing the water from the hot-well through the apparatus, he got rid, not only of the lime in the water, but of the cylinder oil which was in the hot-well. With regard to the sulphate of lime, which seemed to be the only point that was in question, he found, when he commenced his experiments in the United States, that chemists generally did not agree that sulphate of lime was separated by boiling. Their experience had been derived from merely raising water to its boiling point, or 212°, at which temperature the sulphate of lime had not been separated. It was only after experimenting with his apparatus that he became thoroughly satisfied that it was separated at 250° Fahr. At Pittsburg, where there was a good deal of sulphuric acid in the water, and where there was a good deal of pitting as well as scale in the boilers, not only was the scale stopped, but the corrosion also, from the fact that the sulphate of lime, and the sulphuric acid, and all the other minerals and acids, seemed to combine with one another at a high temperature. In reference to that subject, he might mention that brass tubes were used in these heaters. Where the water reached a high temperature in a heater with iron tubes, it seemed to take a particular line across the vertical tubes and eat them through there; it had therefore been found necessary to use brass or copper tubes in the heaters, iron tubes not lasting more than

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water diminishes its power of dissolving sulphate of lime; while the presence of sodium chloride increases that power. As an instance of the latter fact, we find a boiler works much cleaner which is fed alternately with fresh water and with brackish water pumped from the Tyne when the tide is high, than one which is fed with fresh water constantly."

eighteen months. He had been using paint, made of boiled linseed oil and red lead, to coat the inside of the heater shell, putting on about four coats, in order to prevent the acid from taking hold of the iron shell. In some cases, where the acid had been very bad, it had been necessary to make the heater of brass and copper throughout.

With regard to changing the filter, with all his heaters he arranged a travelling crane over the top, with a differential pulley and wheel running on a bar; and by this means he handled the dome and the filter very readily. With a 600 H.P. engine, he had taken the dome off, lifted the filter out, washed out the inside with hose, and replaced it, in less than two hours. The tube-plate was made of cast-iron, and the tubes were screwed into it, usually with sixteen threads to the inch. The Table of percentages, p. 541, was taken from Burgh's Marine Engineering. He had found in actual practice that it was not necessary to use so high a temperature as 290° Fahr. to get separation: 250° or 260° gave practically pure water, though not chemically pure.

ON IRON AND STEEL AS CONSTRUCTIVE MATERIALS FOR SHIPS.

By Mr. JOHN PRICE, of Jarrow.

The object of the present brief paper is to bring into greater prominence than has hitherto been done, the question whether it is more economical, for commercial purposes, to build vessels of steel rather than of iron.

This subject has already received considerable attention, but probably not precisely in its relation to the class of vessels chiefly built in the Tyne district, which are essentially cargo carriers. The author will at once assume that a cargo carrier, whether a sailing vessel or a steamer, has, commercially considered, two functions: firstly to carry her cargo safely and efficiently, and secondly to carry it remuneratively to her owner. It is not pertinent to the present enquiry to consider the first of these functions further, since it is of course granted as a necessary condition to the second. The iron vessel will therefore be taken as the standard of comparison, both as to cost and sufficiency of structure. The question then really is, which of the two descriptions of vessels—steel or iron—can be shown to be the best investment. If we further narrow the question, it takes this form:—in which of the two vessels, taking the dead-weight or cargo-carrying capacity into account, can the ton of dead-weight capacity be got at the lowest cost; for, as this is the unit upon which the ship's earnings are based, it must also be the unit upon which the cost is estimated.

The Company with which the writer is associated has recently built a vessel of the general description given in the Appendix; and it is proposed to take this vessel, as built of iron, for comparison with a similar vessel, but built of steel, so far as it is practicable to adopt steel instead of iron in her construction, thus securing the

reductions allowed from the iron scantlings in use. These reductions take effect only on the material forming the hull of the vessel; and it will be seen from the particulars of the iron vessel in the Appendix that this material amounts to 1179 tons. From the similar particulars relating to the steel vessel, it will be observed that the equipped weight, which in the iron ship is 1740 tons, is 1614 tons in the steel vessel (after allowing for the difference in weight between equal volumes of iron and mild steel); the difference is thus 126 tons. This difference will also be found in the dead-weight carrying capacity, on 22 ft. mean draught. It is only by increasing the dead-weight carrying capacity that any commercial advantage is secured by the owner, in adopting steel instead of iron. This is a point upon which there is no question, assuming of course that the iron ship is in every way a structure fitted for her purpose. We have therefore to enquire under what conditions this 126 tons additional dead-weight capacity has been obtained.

In the first place, in water-ballast trim, the steel vessel would draw 6 in. less water. To put her down therefore to the same draught as the iron vessel would require her tank to be increased in dimensions; and, to preserve the same trim, this must mean increased height of tank. As shown in the Appendix, the additional weight of material used in raising her tank to this height would be 8 tons, which would reduce the available additional dead-weight from 126 to 118 tons. The effect of this increased water-ballast accommodation would further entail the loss of 2900 cubic ft. of stowage capacity, equal to 64 tons of stowage capacity, at 45 cubic ft. to the ton.

The next and most important condition, under which the net increased dead-weight capacity would be obtained, arises from the higher price that would be paid for the steel, as compared with the iron, used in the construction of the hull. Before entering upon this, it may be well to state that the reduction of weight, estimated as due to the use of steel, is 14 per cent. of the weight of the iron hull: which is about the largest rate of reduction found attainable in practice, as recently stated by an eminent Clyde shipbuilder, who has built a very large amount of steel tonnage. The increased cost

of the hull is shown in the Appendix (with the additional cost of the extra weight of tank required for water-ballast, namely 8 tons at £9 12*s.* 6*d.* less discount, and labour at £3 2*s.* 6*d.* per ton, total £100) to be £2656; or an average rate of £22 10*s.* 2*d.* per ton for the 118 tons extra dead-weight capacity. Now we may assume with perfect safety that the iron steamer, such as is described in the Appendix, could be built and equipped ready for sea, including all cost of engines, boilers, &c., for £10 per ton * of dead-weight capacity. This would make her price for 3235 tons dead-weight capacity to be £32,350. Add to this £2656 for the extra cost if the vessel is built of steel, and we have £35,006 as the cost of the steel vessel, for a dead-weight carrying capacity of 3353 tons. This shows the average cost per ton of dead-weight to have been increased from £10 to £10 8*s.* 9*d.*, or an increase of $4\frac{3}{8}$ per cent. In this example therefore we have, in addition to a loss of nearly 2 per cent. of cubic capacity, an enhanced cost of $4\frac{3}{8}$ per cent. per ton of dead-weight capacity.

The question of using steel is sometimes considered differently. It is said that the increase in dead-weight capacity so obtained is a gain which does nothing but earn money, and against which no current charges need be brought, since it is obtained by a simple change of material in construction; and that at any assumed freight, which must be all profit, it will quickly pay for its acquirement. The cost however of this increased dead-weight is seen to be £22 10*s.* 2*d.* per ton, whereas the dead-weight in the iron ship is acquired at the rate of £10 per ton. It would appear at first sight that a complete answer would be given to what has been said about this earning property of the acquired dead-weight, by pointing out that the same effect can be obtained by increasing the dead-weight capacity of the iron vessel at £10 per ton, instead of at £22 10*s.* 2*d.*, the cost per ton of the same increase in steel: with precisely the same property of earning, and immunity from current expenses, and with the additional advantage that the propelling power can be relatively increased at the same rate per ton. If moreover the latter advantage were dropped,

* Vessels are not merely built but *sold* at this rate per ton

increased dead-weight capacity could be acquired in the iron vessel for about £8 per ton. This appears nevertheless to be an entirely fallacious way of looking at the matter. The cost per ton of dead-weight capacity should be calculated on the total tonnage, not on the excess. An owner as a carrier has chiefly to consider the total cost of his carrying capacity; and, whatever be the unit basis of his calculation, the total cost is the aggregate of the average cost per unit. The question an owner asks himself is: "What will this or that ship cost me per ton of dead-weight?" The cost has been shown to be $4\frac{3}{8}$ per cent. less in the case of the iron ship than in that of the steel; and as a purely business matter, the fact that a smaller sum is invested for the same net profit would appear to place the iron sailing or steam-ship, at present, in the more advantageous position as an investment. There is only one condition under which an owner can be placed, where the adoption of steel, at its present cost, can be attended with any advantage; and that is where the dimensions of the ship are absolutely limited by the conditions of her trade. That condition however may be said to exist hardly anywhere in the ordinary carrying trade.

APPENDIX.

Particulars of Steam-Ship taken for Comparison.

Flush deck, with full poop for captain's and officers' cabins—bridge-house over engine and boiler space, with cabins under for engineers—topgallant forecastle for crew and stokers—iron main deck, wood upper deck—hold beams wide spaced—water ballast in double bottom (McIntyre's plan), in after hold, through engine and boiler space, and 20 feet into main hold—deep ballast tank to main deck in after hold—Class 100 A Lloyd's—three decks.

Dimensions.

	Ft.	In.
Length over all	300	0
Length between perpendiculars	290	0
Breadth moulded	37	0
Depth „	25	9
Depth of hold	24	6

	Tons.
Gross tonnage	2285·24
Net „	1494·75

Comparison between Quantities and Cost for Iron and Steel Vessels.

Quantities.	Iron vessel.	Steel vessel.
Total equipped weight........................	1740 tons	1614 tons
„ deadweight on 22 ft. mean draught	3235 „	3361 „
Gross weight of plates in hull	799 „	713 „
„ „ of angles and packing, do.	380 „	340 „
Total weight of iron or steel in hull......	1179 „	1053 „
Weight of water ballast in double bottom	270 „	270 „
Draught in ballast with double bottom full	10 ft. 8 in. mean	10 ft. 2 in. mean
Cubic capacity of hold and between decks	157,000 cub. ft.	157,000 cub. ft.
Height of double bottom in steel vessel (to have the same draught in ballast as iron vessel, not including deep tank)	. .	3 ft. 10 in. from top of keel
Weight of ballast in double bottom about 3 ft. 10 in. deep................................	. .	388 tons
Extra weight of steel in tank...............	. .	8 „
Cubic capacity of holds, with double bottom raised 3 ft. 10 in. from top of keel	. .	154,100 cub. ft.
Cost of Construction.		
Tons. £ s. d.	£ s. d.	£ s. d.
Iron plates ......799 at 6 0 0 less 2½ %	4674 3 0	. .
„ angles & packing 380 at 5 10 0 „	2037 5 0	. .
Steel plates......713 at 9 12 6 „	. .	6691 1 0
„ angles .....292 at „ „	. .	2740 5 0
„ bulb .... 23 at 9 0 0 „	. .	201 16 6
„ packing... 25 at 5 5 0 „	. .	127 19 0
Labour .... at 3 2 6 per ton	3684 7 6	3290 12 6
Total cost	10,395 15 6	13,051 14 0
Deduct Iron from Steel	. .	10,395 15 6
Extra cost of Steel vessel	. .	2655 18 6

Discussion on Iron and Steel for Ships.

Mr. Wm. Denny asked permission to make some remarks on the paper for two reasons: first, because he had had the honour, in the spring of the year, of reading before the Iron and Steel Institute a paper upon practically the same subject, namely the economy of steel ship building; and secondly, because the author had made a most courteous mention of him in a portion of his paper. He was surprised however that Mr. Price, who had quoted him as an authority for the reduction in weight that was possible to be made in a steel vessel as compared with iron, had not followed exactly the figures he had given. In the paper now read it had been stated that the reduction upon 1179 tons of iron was 126 tons; now 126 upon 1179 was only 10·7 per cent., which was a very different figure from 14 per cent., the reduction he had given in his own paper. But further it should have been noticed that the basis which he himself had taken for his percentage was the invoiced weight of iron, including both forgings and rivets; and taking that weight, the 10·7 per cent. became 10 per cent. By that means the author had, to begin with, diminished the reduction in weight due to steel by 28 per cent. He did not know upon what authority that had been done; but he was prepared to show that the whole argument of the present paper rested, first, upon the under-statement of his own reduction; secondly, upon the over-statement of the price of steel; and thirdly, upon the ignoring of the fact that in every steel vessel there was a certain proportion of iron used. Everyone must be well aware that in every vessel there were certain portions that were non-structural: such as the coal-bunkers, the shaft tunnel, engine casings, engine seatings, and many other parts, which no one would dream of making of steel. The reduction quoted in his own paper at the Iron and Steel Institute was worthy of being received and trusted, because it was not merely the result of elaborate and thorough calculations, but also the result of very considerable experience in the actual building of steel ships, and of noting the differences in the weights of the

ironwork. In that paper he had not considered the question of the economy of building cargo ships of the class referred to by Mr. Price; but he had considered the economy of building a very high class of passenger steamer, and also of building a class of steamer which combined passenger carrying and dead-weight carrying. He had not at that time been prepared to go further than to advocate the use of steel for those two classes of steamers; but since reading the present paper he was prepared to go very much further, and to show that it was actually advantageous and economical to build Mr. Price's class of steamers in steel.

To do this, he must first of all make certain corrections. He must deduct from 1179 tons the 14 per cent. he had already referred to, or 165 tons; leaving 1014 tons as the weight of iron and steel which would be used in building Mr. Price's steamer, if she were built of steel. Further, in the 1014 tons there would be 170 tons of iron—a fact of which the author had taken no notice. That gave 170 tons of iron and 844 tons of steel; and prices had to be put upon these. With regard to the price of iron, he would take this at the ordinary mean of the author's prices, or £5 16*s.*; which, less 2½ per cent., would give £961. But the author quoted the price of steel overhead at £9 12*s.* 6*d.* In his own paper before the Iron and Steel Institute he had quoted the price of steel overhead at £9 5*s.*, less 2½ per cent.; and even between the time of writing that paper and the time of reading it the price of steel had fallen considerably, as he had pointed out in closing the discussion upon that occasion. Since then steel had continued steadily to fall. Ten days ago his firm had received offers for more than 3000 tons of steel plates, angles, and bulb bars, overhead: and the highest price quoted had been £8 17*s.*, the next £8 15*s.*, and the lowest £8 14*s.* 9*d.*, all less 2½ per cent. Taking £8 15*s.* and deducting 2½ per cent., the price of the 844 tons of steel was £7200: making a total, including the iron, of £8161.

He was now going to give the iron vessel an advantage. The labour upon the iron vessel had been quoted in the present paper as £3684, and the labour on a steel vessel had evidently been taken at the same rate per ton, and so had been made £3290 roughly. That was an entire mistake: a steel vessel could not be built more

cheaply than an iron vessel of the same dimensions; the total labour would be the same; and he had taken care, in his own paper, not only to show this, but also to give the reasons for it. He would therefore put down the same wages as for iron, or £3684, and add them to the £8161, making a total of £11,845 as the cost of the iron and steel and of the labour, in the steel steamer. Deducting from that the author's estimate for the same items in the iron steamer, or £10,396, there was a difference of only £1449 in favour of the iron steamer.

He was now going to give the iron a further advantage. In taking the difference between the gross weights, or invoiced weights, of the iron and of the steel, the author had made no deduction from them for scrap. But off the 165 tons of iron saved in the steel steamer he would now take 9 per cent., which was the allowance made in his own yard for scrap; that left 150 tons as the net saving of weight. He had now £1449 divided by 150, or £9 13*s.* 2*d.* as the price per ton of the extra dead-weight capacity. So that the additional dead-weight capacity in the steel steamer could be gained for 6*s.* 10*d.* less per ton than the original dead-weight capacity of the iron steamer, which had been assumed in the paper at £10 per ton. This result, as would be seen, was a clear and definite advantage in favour of building in steel.

He had made a point of attending the present meeting in order to show the mistakes in the paper, and to prevent those who represented the great ship-building industry of the Tyne from being misled upon the important subject of steel. He hoped his remarks would be received not in any way as those of an opponent to the author. He had no wish to be an opponent to any east-coast builders, and his only desire was to show where he differed from the paper that had been read.

As to the question of water-ballast, he acknowledged frankly that the author had made a decided hit. But if the extra tanks for water-ballast were made in a structural cellular form, then, although losing capacity, the shipowner would get a deduction in tonnage, which would to a great extent cover the loss. And even supposing the extra capacity to be wholly lost, it was well known that there were

many steamers, carrying ore and so forth, in which that would be no disadvantage at all.

Mr. B. Martell thought very little more was to be said upon the subject, since Mr. Denny had so clearly put forward what had also been running in his own mind. He had been very much surprised to find that, although the author accepted the statement of 14 per cent. as the saving in steel over iron, yet in giving the weights he had put down what amounted to a percentage of 10·7 only; but he might perhaps be able to explain that. It appeared to himself it could be very simply shown in another way that the commercial advantage was really, on the face of the figures, in favour of the steel ship. Taking, for instance, the ship which the author had given, its gross earnings would amount to, say roughly, £12,000 a year; and supposing the working expenses to be £9000, that would leave a net profit of £3000, or less than 10 per cent. on the £32,350 total cost of the iron ship, as given in the paper. Now the working expenses of a steel ship would be nearly the same, say £9000; but allowing for the additional 165 tons dead weight, if the ship were employed in dead-weight carrying, the gross earnings would be £12,600, and that additional £600 would represent a profit, on the £2760 additional cost of the steel ship, of 21½ per cent. instead of 10 per cent. So that it was clearly shown on the face of it that, if the ship were fully employed in carrying the additional dead weight throughout the year, the profits would be much larger in the steel ship as compared with the iron ship.

With reference to the double-bottom water-ballast he did not agree with Mr. Denny. He thought that question ought to be eliminated from the subject, because in his opinion there were many ways of meeting the increased water-ballast required in a steel ship. In fact the author himself had shown this in some ships he had recently built, in which he had fitted the water-ballast in the form of a deep tank, where it could be utilised either for water-ballast or for cargo purposes. It was not necessary to raise the inner bottom; some other system might be adopted to give the same internal capacity.

It seemed to him that there was a different cause which deterred shipowners from going into steel more largely than they did. For many large steamers they could not rely on dead-weight carrying; they had to take measurement goods to a large extent; and while the steel ship was more expensive, there was no advantage where it had merely to carry measurement goods, because there was no greater measurement capacity in the steel than in the iron ship. All were agreed that a steel ship was in itself a far better vessel than an iron ship. As to the quality of steel, its uniformity, its ductility, and its strength, he thought that question was settled. They had had sufficient experience to know that for all practical purposes it was generally uniform in quality, that it was a magnificent material in regard to ductility and strength, and that ship-iron was not to be compared with it. He hoped steel manufacturers would be able to bring down the price of the material, so that steel ships might be built to carry measurement goods as economically as iron ships; and then, in the course of a little time, it would be a rare thing for an iron ship to be built.

Mr. JOHN ROGERSON was much pleased that this paper had been brought forward; and would first refer to the commercial question, which Mr. Denny had also treated of. The following were the cost of building, the dimensions, the cost of sailing, and the earning power, of a steamer going to Bilbao :—Length 216 ft. over all, beam 30 ft., depth of hold 16 ft. 3 in., cargo 1300 tons on 14 ft. $7\frac{1}{2}$ in. draught of water; builders' price (in 1877) in iron £17,000, in steel £18,350, showing a difference of £1350. The gross gain due to the use of steel was as follows :—Extra freight at £1 per ton on 70 tons of coal outwards to Bilbao and of iron-ore back again, giving as actual amount received on twelve voyages in the year, over and above the freight on a similar vessel built in iron, £840 per annum. The extra cost was :—Extra insurance £148 10*s.*; loading and discharging extra cargo, at 2*s.* per ton, £84; 5 per cent. brokerage £42; making £274 10*s.* to be deducted from £840, and thereby leaving a net profit of £565 10*s.* on the £1350 extra outlay. It was possible therefore, looking at the matter from a commercial point of view, that a steel

ship would not cost very much more than an iron ship, while it would carry more cargo and earn more freight.

But the main points to which he wished to direct attention were that the steel ship would draw less water, that it would cost less for repairs and renewals, and finally that it would last longer; and therefore as a permanent investment it was better to use steel than iron. He exhibited a piece of Cleveland ironstone, from which one-half at least of the tonnage of the world in iron ships was now being produced. If plates made from that ironstone for iron ships were examined, and then the steel was examined which was put into the steel ships—specimens of both of which materials were exhibited—so great a difference would be found that he believed mechanical engineers would on all points discover the advantages of using steel instead of iron. He was himself interested both in Cleveland iron and in Weardale iron and steel, of which he exhibited specimens. Some twenty years ago he had built twenty steamers of iron for running on the river Tyne; but the cost of repairs and renewals had been so great that in the twenty years the hulls of all the steamers had been at least once replaced in respect of cost. A new era had now commenced. Some of the members would go down the river that afternoon in an iron steamer, and some would go in a steel steamer, the *Charles Attwood*, in which the hull, boilers, boiler tubes, and all the working parts of the engines were made of steel, the boilers costing little more than if of iron. He intended to renew with steel the present line of iron passenger steamers now running on the Tyne. The plates of the steel ships, should any paint be rubbed off their surface, were not so liable as iron plates to become pitted by corrosion. In order to obtain some idea of the comparative corrosion of iron and steel, experiments had been made at the Tudhoe Iron Works on the specimens now exhibited of iron and steel plates, of the chemical composition given on the following page. These specimens were originally 2 in. square by $\frac{3}{8}$ in. thick, and had been immersed in a bath of water containing 1 per cent. of sulphuric acid, and the loss in weight had been recorded every twenty-four hours. In seventeen days the mild steel had lost only 4·8 per cent. of its weight, while the iron samples had lost from 35 to 79 per cent.

Composition of experimental Steel and Iron Plates.

Material.	Steel.		Iron.		
	Mild.	Medium Hard.	Tudhoe Best Best.	Tudhoe Crown.	Common.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Iron	99·354	98·400	99·000	98·900	98·800
Carbon	0·115	0·330	Trace	Trace	Trace
Manganese	0·504	1·008	0·216	Trace	Trace
Silicon	0·055	0·065	0·111	0·107	0·177
Sulphur	0·028	0·022	Trace	Trace	0·008
Phosphorus	0·037	0·075	0·165	0·217	0·532
Copper	Trace	Trace	Nil	Nil	Nil

Mr. W. John thought, with Mr. Denny, that in the type of cargo ship where dead weight was the basis steel had the advantage. In the case of large passenger vessels there was a still greater advantage in favour of steel, if dead weight were the basis. For instance, in a vessel which he had to deal with a few days ago, the increase in available dead weight by the use of steel was as much as 11 per cent.; whereas the increase in the cost of the vessel was not more than 6 per cent. So far as dead weight at present prices was concerned, in his opinion Mr. Denny's figures were nearer the mark than Mr. Price's; and he believed the advantage was in favour of steel. But the difference was a question of slight fluctuations in price of material; and it was quite evident that no one could say whether steel or iron was going to be the leading material in the immediate future. He thought the probabilities were that steel would come down in price, and that it would be very rapidly introduced on the north-east coast to a larger extent even than at present on the Clyde; because, with their dead-weight carrying boats, the advantage was in that direction.

As to water-ballast, he thought the height of the double bottom in the steel vessel need not be increased to the extent of immersing the vessel as deeply as she would be if of iron; because if a certain amount of weight were taken out all over the hull of the vessel, then clearly the steel ship would be a much stiffer and safer vessel than the iron ship, and could do with less immersion. To say that the water-ballast should be increased, for the purpose of putting the steel ship 6 inches deeper, was, he thought, an over-statement.

Allusion had been made in the paper to there being two ways of looking at the matter. On the one hand, taking ships of the same size, there was a certain increase in the dead-weight carrying capacity with a steel ship; and on the other hand, of two vessels costing the same, the iron vessel was larger than the steel. One of these methods of looking at the matter the author called fallacious. He himself however did not think that either was fallacious. Either it was advantageous to build a steel ship, looked at in whatever way they pleased; or it was disadvantageous. He thought the result would come out exactly the same, whether the question was looked at from one point of view or from the other. If a larger ship were built in iron, the working expenses would be increased. That point the author had indeed touched upon, in saying that the size and the propelling power could be increased at the rate of £10 per ton of dead-weight capacity; but then the working expenses were increased at the same time, so that it came to the same thing.

He would make one remark about the quality of steel, as compared with iron. A short time ago his firm had contracted for a vessel in iron, and it was a stipulation that the iron should be capable of stretching 5 per cent. with the grain and $2\frac{1}{2}$ per cent. across the grain; and they had had to pay an extra price to get that very small percentage of elongation in the iron. Steel, on the other hand, could easily be got to stretch 20 per cent., without extra cost. He thought this showed how very much more reliable steel was; and also that steel manufacturers willingly submitted to tests, while iron manufacturers were rather shy of them. With regard to insurance, he was not at all certain that, as they got further on, and had more experience with steel vessels, they would not find a difference in rates

between the insurance on steel and that on iron vessels. He thought this was another element of the future which they might look forward to.

Attention should also be given to the probable behaviour of an iron ship and of a steel ship when knocking about on rocks, or on a hard bottom. The best example he could give was that of a vessel built by Mr. Denny's firm. It ran on the rocks, and the plates were bent up to such an extent that there was no doubt, if the vessel had been built of iron, she would have been a total wreck, and probably there would have been great loss of life; but instead of that, she was got off without making a drop of water. There were several cases on record of that kind.

Mr. E. WITHY said Mr. Denny's figures came very much nearer to his own experience last year in building a steel vessel than those given in the paper. With regard to the behaviour of a steel vessel on the rocks, as compared with an iron vessel, he might mention that a case had occurred in the Tees a few weeks ago, where a steel vessel, built on the Tyne, sat on a large stone, and doubled up her plates considerably, and even broke some internal floor plates. The underwriters' inspector who looked at the vessel stated in his official report that if she had been built of iron she would inevitably have cracked her plates and filled with water, and probably cost the underwriters thousands of pounds.

He understood the main question raised in the paper to be—Was it at *present prices* desirable as a commercial investment to build a steel instead of an iron vessel? The author answered that in the negative. But if a steel vessel were offered to the author at the same price as an iron vessel, no doubt he would say: "Well, the steel vessel will yield a greater net annual profit, and therefore I will take the steel vessel." The author however did not think it profitable to pay the extra price now required, and had suggested as an alternative that the iron vessel might be increased in size; but that was open to many objections. In the first place, to increase the carrying capacity of a vessel by 100 tons, the gross displacement must be increased not only by that 100 tons, but also by as much more as would allow for the

extra weight of the increased size of hull. Then there would come some point when the power must be increased, in order to get the same speed; and the gross displacement would have again to be increased in order to carry the extra weight of engines. The net register tonnage upon which dues were charged would also be greater. But there was another point even more important. In his own experience most iron cargo-vessels were built as near to Lloyd's grades as possible; and they could not get 6 in. more in length, or 3 in. in beam, or 1 in. in depth, without exceeding the magical line drawn by those rules. The moment that line was exceeded, the weight of the vessel was very largely increased, by her scantlings having to be made thicker all over. The steel steamer to which he was about to refer was so circumstanced. He quite agreed that it did not follow that, because large liners would pay if built of steel, therefore all cargo-boats would pay if so built.

Last year he had built a steel screw steamer—the *Cyanus*—not however one of the most favourable type for showing the advantages of steel. She was a single-deck vessel, with a long full poop and top-gallant forecastle, the poop and bridge-house being joined together. That meant a vessel of which a large portion was of light scantling, and upon which the full reduction allowed by Lloyd's rules could not be got. In a flush-deck vessel, with main scantlings going to the upper deck, the thicknesses could be reduced almost throughout: so that his ship, not being of this type, was not one of the most favourable specimens. The results were that she carried 94 tons, or 4 per cent., more dead weight, and cost between £1500 and £2000 more than if built of iron. He might mention a few facts relative to the reductions. He found that the amount of iron not replaced by steel was 15 per cent.; but the steel which replaced the 85 per cent. of iron weighed 14 per cent. less than the iron did; the *overhead* saving, by the use of steel and iron as compared with iron only, was thus only 12 per cent.

Now 4 per cent. additional dead-weight capacity might appear a small item, but it was really much more important than it might seem at first sight. The vessel carried about 2400 tons dead-weight, and he would assume that on a certain voyage she would carry

300 tons of fuel; that would leave 2100 tons of cargo. There must be a certain portion of that cargo, at the freight earned, which would be required to pay for the working charges of the ship. Supposing the freight on 1500 tons was so absorbed, the *profit-bearing* portion of the cargo would be only 600 tons; and upon these 600 tons the increase of 94 tons was a much larger item than the 4 per cent. itself looked at first. Another point was that the steel vessel would show to the greatest advantage in the hardest times: when the iron vessel would run and just make both ends meet, the steel vessel would have those 94 tons extra cargo mostly to the good.

For convenience of comparison he had drawn up a statement of the leading particulars of the *Cyanus*, in the same form as that given in the paper. The general result would be seen to be that the net weight of steel and iron in the *Cyanus* as actually built was 688 tons, costing £6966; while the estimated weight and cost of the iron, had she been built wholly of iron, would have been 782 tons and £5187. Hence the steel vessel weighed 94 tons less, and cost £1779 more, than the iron vessel would have done.

Particulars of Steel Screw Steamer "Cyanus."

Single-decked, with long full poop and bridge-house in one—topgallant forecastle—main and poop decks of steel—cellular double bottom all fore and aft—classed 100 A 1 at Lloyd's.

Length over all	273 ft. 7 in.
Length between perpendiculars	264 ft. 5 in.
Breadth moulded	34 ft. 2 in.
Depth moulded	19 ft. 6½ in.
Depth of hold	18 ft. 6 in.
Horse power of engines	150 H.P.
Gross tonnage	1635·49 tons.
Net ,,	1060·63 tons.
Total equipped weight	1133 tons.
Total deadweight on 18 ft. 4 in. mean draught	2434 tons.
Weight of water ballast in double bottom	431 tons.
Mean draught in ballast with double bottom full	9 ft. 3 in.
Cubic capacity of hold and between decks	103,410 cub. ft.
Height of double bottom above top of keel	3 ft. 6 in.

Cost of Steel and Iron in "Cyanus" (taking Mr. Price's values).

		£ s. d.	£
Steel plates	405 tons net at	9 12 6	5169
„ angles	132 „	9 12 6	
„ rivets	33 „	13 0 0	429
Iron plates	54 „	6 0 0	324
„ angles	16 „	5 10 0	88
„ packing	12 „	5 10 0	66
„ rivets	4 „	8 5 0	33
„ for smiths	24 „	7 10 0	180
„ forgings	8 „		241
		Loss by waste	436
Total Steel and Iron	688 tons net.	Cost	£6966

Estimated Cost of Iron, to build same vessel wholly in Iron (taking Mr. Price's values).

		£ s. d.	£
Iron plates	524 tons net at	6 0 0	3144
„ angles	177 „	5 10 0	973
„ packing	13 „	5 10 0	72
„ rivets	36 „	8 5 0	297
„ for smiths	24 „	7 10 0	180
„ forgings	8 „		241
		Loss by waste	280
Total Iron	782 tons net.	Cost	£5187

It seemed to him that the change from iron to steel vessels was analogous to that which had taken place so extensively of late years, in regard to engines. It had been found better to condemn engines of the old-fashioned type which were not nearly worn out, and to incur a large capital outlay in putting in engines that would burn very much less fuel. Mr. Marshall's paper on the marine engine had quoted the words of Mr. Holt, that the actual *disbursement* for coals was not a very important item. But, however that might be, he himself thought the saving in *weight of coal to be carried* on a given voyage, due to a better type of engine, was a very important item, and was just the question between iron and steel for ships.

The steel vessel *Cyanus* had of course no more stowage capacity than if built of iron; but when completely full, she would draw 5 in. less water than an iron vessel. When in ballast also she drew $5\frac{1}{4}$ in. less water than an iron vessel; but he agreed with Mr. Martell that this was an objection easily got over, and he thought the author's way of raising the tanks all fore and aft was the worst way in which it could be done for a steel vessel.

He might mention that not a particle of steel, either in testing or working, had been condemned throughout the building of the *Cyanus*, which had been his first experience in handling steel; it had not been worked in any special way, but none of it had been broken or condemned. That would be an item of economy in the future in favour of the production of steel vessels. A few steel plates and angle-bars had been left over from that vessel; and wherever there was difficult flanging to be done for an iron vessel, for instance in the angle-iron collar round the lower end of the rudder trunk, he had frequently found that the men had taken up a piece of the steel for making it.

He had been responsible to the owners of the *Cyanus* for recommending that she should be built of steel instead of iron; and the ideas that ran through his mind might be summed up in a sort of balance-sheet, showing the differences in the net earnings of two steel and iron boats of the same dimensions, going on the same voyages. First, on the credit side for steel there was 4 per cent. more dead weight carried, and therefore the same percentage of increase in the gross earnings. On the debit side there was, first, the cost of loading and discharging that extra cargo; secondly, brokers' and merchants' commission on that cargo; thirdly, the insurance upon the freight of the extra cargo (or, if the owner did not insure his freight, he ran a risk of losing 4 per cent. more freight than in the case of an iron vessel); fourthly, there was the insurance on the extra capital invested, which might be 9 per cent., assuming that there was no reduction in rates for a steel vessel, which however he believed would come; and lastly, there was the depreciation upon that extra capital. He submitted that this gave a fair comparison of the net earnings of the two vessels. But a slight

allowance must be made in regard to time: the additional 94 tons of cargo could not be loaded and discharged in no time; therefore a steel ship would take a little longer over each voyage. When these points had all been taken into account, it only remained to be considered whether the net earnings of the steel vessel would pay as good a percentage upon her value as the net earnings of the iron vessel would upon hers.

Mr. D. Adamson proposed to say a few words on the question of corrosion, which had alarmed the whole public through one or two papers that had been read; and which must more or less affect the application of steel or iron to ship-building and steam-boiler purposes. A paper had recently been read on the subject by Mr. Phillips, before the Institution of Civil Engineers (Proceedings, vol. lxv., p. 73); and another paper had also been read by Mr. Parker, of a less alarming character, before the Iron and Steel Institute (Journal 1881, p. 39). He himself looked at the subject of corrosion somewhat differently from the way in which it had been investigated by Mr. Phillips. Experiments had been carried on by Mr. Phillips on thin plates of iron and steel, immersed in salt water, the thickness amounting to only one-tenth of an inch or so, while corrosion was operating on both sides. Hence under the corroding influence of salt water such plates would show double the extent of corrosion, in consequence of their being attacked on both sides. He was not aware that a boiler or ship was subject to a continuous corrosive influence on both sides at one and the same time. Whilst the thickness of those plates had been only one-tenth of an inch, he thought he was entitled on the other hand to take a thickness of plates not uncommonly used by himself—namely 1 in. If the percentage of loss was, on the $\frac{1}{10}$-in. plates, 20 per cent. for both sides, the 1 in. thickness brought the reduction, in proportion to the weight, down to only 2 per cent. for both sides, or 1 per cent. for one side: so that, in the comparison of the thicker metal with the thinner, the percentage ceased to be alarming.

But there was a further position that he wished to take. In all cases, according to his experience, where iron and steel had been

subject to corroding influences, the steel was attacked in a greater degree in the first instance: but if the corrosive influence were allowed to operate for a longer time, then, instead of the steel losing more than the iron, it positively lost less. Hence not only must the thickness of the metal be taken into account, but also the length of time the experiment had been carried on. According to the experiments already referred to (page 563), from which samples were exhibited, and which had been confirmed by other experiments of his own, a piece of puddled iron, 2 in. square by $\frac{3}{8}$ in. thick, lost in seventeen days' immersion in a bath of water with 1 per cent. of sulphuric acid about 85 per cent. of its weight. Mild steel, suitable for ship or boiler-plate purposes, lost about 8 per cent. Harder steel or bridge metal—metal that would carry 55 tons per sq. in.—lost less than mild steel during the early part of the experiment; but after some days the position was altered, and the milder metal lost less. Pure iron—which was very difficult to get and enormously costly—lost the least of all, not more than 7 per cent. in the same time. In examining the question to the best of his ability, and consulting others of large experience, he had come to the conclusion, that it was not a question of a certain definite action tending to destroy the iron as a whole, but that it would appear on the whole that the material which suffered most from corrosion was that which contained the largest amount of foreign matter; and this applied, whether the foreign matter was associated with the iron by chemical union or by mechanical admixture like cinder, the latter suffering the most in the same time.

Leaving that subject, he would pass on to the question of dead weight. The reduction of 14 per cent. allowed for steel was founded on certain tests, excellent he had no doubt in some way or other; but it was a misfortune to include among them what was called the cold-water test. He failed himself to comprehend why shipbuilding steel should be subjected to a test by plunging into cold water, when it was never applied under those conditions. He could quite understand, and indeed he was quite satisfied, that there was an exceptional compound — and if his friend, Mr. Cowen, of the Weardale Iron Works, was present, he would bear testimony to it—

which was improved by being plunged into water, acquiring thereby a higher power of endurance than if it had simply been annealed. That was not the system under which ship-plates were used; and this test was beside the question, and had rather a tendency to lead astray than otherwise.

In comparing iron and steel with regard to their mechanical properties, there was often an idea that they both possessed a certain average tensile strength or elongation in all directions. Taking for instance a piece of angle-iron or flat bar, and pulling it asunder longitudinally, the common commercial iron of this country would break at about 22 tons per sq. in. But in no case that he knew of had the same iron been pulled asunder transversely; and yet how often must that iron, as used for shipbuilding, be pulled transversely, especially in the angle-bars. In his experience in that matter the same bars which would withstand 22 tons per sq. in. in the longitudinal direction would give way transversely with 8 tons only. That was due to the cinder, which would probably exist in the original pile in the form of little patches at certain points, but would be elongated in the longitudinal direction by rolling, forming interlacings of a very minute character, which assisted to produce the general conditions of what was called fibre. When torn transversely, there was no elongation and no warning, but the iron broke down with abruptness. Plates followed the same law, materially depending on the same condition, namely what quantity of cinder existed at any given point. At a previous meeting (Proceedings 1880, p. 93) Mr. Head had stated that the average tensile strength of good plate iron was something like 22 tons per sq. in. longitudinally and 18 tons transversely. For testing, he had himself generally bought plates commercially, without the manufacturer knowing that they were for testing; and his experience was that in iron plates there was a tensile strength of only about 18 tons per sq. in. longitudinally, and that the strength often dropped down to 13 tons transversely. That was a very different thing from steel plates, though much better than the mere 8 tons he had found as the transverse tensile strength in bars or angle-irons. There was not an engineer of experience who did not know of disastrous calamities arising from some cause altogether

exceptional; and he held that this cause was a weakness in the transverse direction, due to the cinder interlaced in ordinary bar and angle-iron. Steel did not follow such a law; it possessed a tensile strength of from 28 to 32 tons per sq. in., as used for boilers and ships, and did not vary more than 2 per cent. whether tested longitudinally or transversely. Hence with angles or flat bars the dimensions to stand lateral strain might be much reduced in the case of steel, as compared with iron, for the framework of steel ships and similar structures.

Mr. Price, in reply, said he had no reason to complain of the discussion; on the contrary, he had some reason for satisfaction in having brought the subject before the members. He was conscious that he stood before them, in the face of the figures which had been given, very much in the character of a culprit; but he felt satisfied that he should rehabilitate himself, before he had done. He had tried to give an entirely different character to the discussion from those which had taken place on previous occasions upon similar questions; and had attempted to look at the subject purely from a shipowner's point of view. The brief and simple paper that he had submitted was entirely with this object, that the shipowner should be able to take it up, and to deal with the question, what would it cost to carry a ton of dead weight in steel or in iron; so that shipbuilders might be able to put into the shipowners' hands some reliable data, upon which to decide this important question for themselves.

He wished first to bear willing testimony to the indebtedness of the community to the efforts of Mr. William Denny, in bringing forward the subject from time to time. He thought also that Mr. Denny owed something to him, in that they had been able to approach the subject that day without having the steel manufacturers assailing Mr. Denny, as they had been provoked to do on the last occasion; and without having Lloyd's surveyors defending themselves, as they also had been provoked to do on a former occasion. They had had very much of a free discussion, and the result had been highly advantageous to those most interested, namely themselves.

Mr. Denny had commenced by saying that in his own paper he had not had cargo ships in his mind. Perhaps he might refer to a single paragraph in Mr. Denny's paper, both as bearing on the question of cargo carriers, and also as having some reference to the figures that had been given. Mr. Denny had now attempted to show that a steel cargo-carrying ship could be built cheaper than an iron one; yet in his paper in the spring of the year (Iron and Steel Institute Journal, 1881, p. 59) he had shown that the increase of dead-weight capacity in a cargo carrier built of steel was obtained at a cost about £2 per ton higher than the cost of the dead-weight capacity in ordinary iron dead-weight carriers: although he had added that—inasmuch as insurance and depreciation would be the only charges against this higher cost, while neither coals nor current expenses nor dues came against it—there was no doubt the increase of dead-weight capacity would be a source of very decided clear profit in the working of the steel steamer. To-day was therefore not the first time when the dead-weight question had been considered, and in relation to the particular elements which entered into the question of what the ship would cost.

He had now to defend his own figures, and to show that Mr. Denny's figures were not fair to the iron ship. With regard to the price of steel, he would take Mr. Denny's lowest figure of £8 14*s.* 9*d.* per ton on the Clyde, which would be £9 4*s.* 6*d.* at Newcastle. Similarly the price of £5 16*s.* for iron was in the Tyne district, not in Glasgow. He quite agreed that it was a question of pounds, shillings, and pence; but shipowners did not go everywhere and anywhere to buy ships: they had to deal with the matter as affected by the prices in their own neighbourhood. Having therefore got a *bonâ fide* quotation from the Steel Company of Scotland at £9 12*s.* 6*d.* all round for angles and plates, and having taken the selling price of iron at Middlesbrough, he considered that he had acted fairly in bringing forwards the figures given in his paper. If he had gone to Middlesbrough he could perhaps have bargained for 7*s.* less on the iron; and if to Glasgow for 5*s.* less on the steel: in the former case the 7*s.* reduction would have been upon £5 16*s.*, and therefore a much larger proportionate reduction than the 5*s.* off £9 12*s.* 6*d.*

As to the quantity of iron in bunkers &c., referred to by Mr. Denny as not having been deducted in the steel ship, it was simply a mistake altogether to imagine that this had not been properly allowed for in the paper: in fact it was stated (p. 554) that the substitution of steel for iron was limited to the hull of the ship.

To show the kind of reasoning with which the subject had been burdened, he should like to give one example. In Mr. Denny's recent paper already referred to a comparison had been made between an iron ship and a steel ship. One of the elements of cost was of course the length of the plates. In an iron ship they were ordinarily made 10 ft. or 12. ft. in length: that was the standard length for ship-plates, and it was satisfactory. But in Mr. Denny's paper (Iron and Steel Institute Journal, 1881, p. 64) steel plates were assumed of 16 ft. length; and it was argued that if they had been made to that greater length in iron they would have cost so much extra, and therefore that the iron ship should be charged with this extra cost, a cost which had not really been incurred.

With regard to the observation that he had taken 126 tons as the saving due to using steel, and not 165 tons, he was indebted to Mr. Denny's paper for his reason for thus reducing the net saving due to steel: for in that paper * the reduction upon scantling sections by the

* The portion of Mr. Denny's paper referred to here, and subsequently on page 579, is as follows (Iron and Steel Institute Journal, 1881, pp. 54–56):—

"The experience of my firm is that by building a steamer in steel instead of iron, a saving averaging 13½ per cent. upon the weight of the iron can be effected. The variation in the percentage is very slight, the highest saving we have yet made amounting to a little over 14 per cent., and the lowest to 13 per cent. In an appendix are given the items of the invoiced iron weight of a spar-decked steamer of about 4000 tons gross, with their cost at present current prices of iron, and in the same appendix are given the same particulars for the vessel constructed in steel. You will notice that the amount of the invoiced iron in the iron steamer is 2333 tons, and of the invoiced iron and steel in the steel steamer 2030 tons, the difference being as nearly as possible 13 per cent. upon the weight of iron. This is rather less than the average reduction mentioned above, and the diminution of the percentage is due to the fact that in a spar-decked vessel, the iron scantlings being already to some extent reduced, it is impossible in employing steel to reduce them in the same ratio as in a three-decked or full scantlinged vessel.

substitution of steel was assumed at $18\frac{1}{2}$ per cent.; but it was further pointed out that the reduced weight so arrived at had then to be increased by $2\frac{1}{2}$ per cent., to allow for the difference of weight between equal volumes of iron and mild steel. Now 165 tons treated in that way became very nearly the 126 tons given in his own paper (p. 554) as the difference between the 1740 tons equipped weight in the iron ship and the 1614 tons in the steel vessel; and it would be seen he had there pointed out that this result was arrived at after allowing for the difference of weight between equal volumes of iron and mild steel.

This he thought might suffice to dispose of the points raised in relation to the actual figures given in his paper. The real point at issue, he contended, had not been touched by the figures either of Mr. Denny or of Mr. Rogerson. The steel ship mentioned by Mr. Rogerson had been a bargain; and bargains did not rule transactions that took place from day to day. The earnings upon his first ship, where he showed a large return upon 70 tons extra carrying

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In the case of an awning-decked steamer, which, as compared with a three-decked vessel, is further reduced in iron than a spar-decked steamer, the percentage of reduction in steel would be slightly under 13 per cent., and for similar reasons. You will notice that in the weight of iron and steel, required for building the steel steamer, there are 340 tons of iron which are employed in the building of deck-houses, coal-bunkers, engine and boiler casings, coal-shoots, coamings, and engine and boiler seatings. On this no reduction is made; and if we add to this weight 41 tons of forgings, which, although of scrap steel, it is not the practice of my firm to reduce, we have 381 tons of the original iron weights not subject to any reduction, thus leaving only 1952 tons subject to reduction.

"If we assume the amount of reductions permitted by Lloyd's to be $18\frac{1}{2}$ per cent. upon scantling sections, we will not be very far wide of the mark, as although the rules permit a reduction of sectional area of 20 per cent., and in some cases a little more on certain portions of the structure, on other portions, such as the beams, frames, and reverse frames, it is impossible to approach this. If we now deduct from the 1952 tons of iron subject to reduction $18\frac{1}{2}$ per cent. for reduction of sectional area, we have 1591 tons; but this weight has to be increased by $2\frac{1}{2}$ per cent., the amount of the difference of weight between equal volumes of mild steel and iron. This adds 40 tons, making the correct weight 1631 tons. Adding to this the 381 tons of iron common to both the iron and steel steamers, we have a total of 2012 tons, or very nearly the correct amount estimated in the appendix as the weight of the steel and iron in the steel steamer."

capacity, had been estimated much in the manner referred to in the paper, namely by taking the increase in the earnings and putting almost the whole of that increase as a dividend upon the increased cost of the steel ship. That was beside the question, if it did not tally with the results of the method laid down in the paper, as that upon which an owner ought to proceed. The owner, as a carrier, wanted a certain amount of capacity. A unit of capacity was the unit upon which he reckoned his earnings, and that was the basis upon which he should calculate his cost and his investment. No owner having a steel ship of 3500 tons total capacity—200 more than if she were an iron ship—would debit her with 3300 tons at one price and 200 tons at a higher price; he would of course take the average cost per ton of the whole dead weight. It did not matter arguing upon the percentages, and upon the net effect produced on the year's earnings by that small accession to the tonnage. If it could not be shown that the net cost per unit of capacity was lower, the ship could not be cheaper; if it was lower, the ship was cheaper. In this he was only stating a truism, which was the basis of every day's business, and which they invariably proceeded upon.

He should like to clear himself from the suspicion that he had any antagonism to steel. No one had done more than himself, so far as he could, in endeavouring to arrive at an understanding upon which he could advise, when his advice was asked, on this question. What he wanted to arrive at was to be able to tell which was the cheaper ship; and it must be remembered that, in the comparison between the two, p. 555, it was the selling price of the iron ship that was taken, including the builder's profit, while with the steel ship it was the bare cost of construction only. But, so soon as a steel ship could be built as cheap as an iron ship, giving the owner the advantage of the increased dead weight, he should advocate it as strenuously as possible. He was not an advocate of iron ships as against steel, but quite the contrary; he believed steel was the better material; and in saying so he thought he showed himself fair. What they had to endeavour to do was to find out which was the best investment; and having done so, to

give their advice irrespective of what might be the bearing of the question upon their own interests.

Mr. Denny asked to be allowed to offer an explanation. With regard to the use of plates of 16 feet length in the iron ship of which he had given the particulars in his own paper (Iron and Steel Institute Journal, 1881, p. 64) it would be found that the cost of the iron ship had there been worked out simply for ordinary plates, without including the extra payment for the longer plates: so that there was no unfairness to the iron ship, for which the cost of the iron was in that way made out at only £14,501. The omission of the extra payment was rendered quite clear by the note added as follows:—"Owing to the plates in this steamer being 16 feet long, 610 tons of them exceed the limits allowed by iron makers in size and weight, and on this an extra payment of £650 would be required. The true cost of the iron would therefore be £15,151 instead of £14,501. The limits allowed by the steel makers would entail no extras on this vessel."

There was another point which ought to be made clear. In the portion of his own paper from which both Mr. Price and himself had already quoted * it was shown that, carefully estimated, the weight of iron in a spar-decked iron steamer of 4000 tons gross was 2333 tons, while the weight of steel and iron in the same vessel built of steel was 2030 tons: being a difference of as nearly as possible 13 per cent. upon the weight of the iron. It was further pointed out that, on account of the initially lighter scantlings of spar-decked steamers, the percentage of reduction was lower in this class than in the three-decked class—to which latter belonged the example taken in the present paper. In the approximate explanation then given of how the above reduction of 13 per cent. came about, full provision was made for the difference of 2½ per cent. between the weights of equal volumes of iron and mild steel. In the same way the 14 per cent. of reduction, attainable in the heavier-scantling three-decked class of steamer dealt with in the present paper, fully covered all

* See foot-note on pages 576–7 *ante*.

consideration of the same $2\frac{1}{2}$ per cent. difference. This the following figures would show clearly. From the 1179 tons of iron in the hull of the author's iron vessel, the deduction of 14 per cent., or 165 tons, left 1014 tons as the weight of iron and steel, if the same hull were built of steel. Now deducting from 1179 tons the 170 tons which he had previously assumed as the weight of iron that would not be replaced by steel, and consequently would not undergo reduction of section, there would remain a balance of 1009 tons as the weight of iron that could be reduced in section through being replaced by steel. Assuming $18\frac{1}{2}$ per cent. as Lloyd's allowance for reduction of section in steel, this would give a deduction of 187 tons from the 1009 tons of iron, leaving 822 tons of steel: which, when increased by the $2\frac{1}{2}$ per cent. greater specific gravity of mild steel, became 843 tons. Adding to this the 170 tons of unaltered iron, the final result was a total of 1013 tons as the joint weight of the steel and iron in the author's steamer when built of steel. This was within one ton of the weight of 1014 tons, which he had obtained above by simply deducting 14 per cent. from the original 1179 tons weight of the iron hull.

ON SLIPWAYS.

By Mr. WILLIAM BOYD, of Wallsend-on-Tyne

In responding to an invitation to read a short paper on the modes used for hauling up vessels on slipways, the writer wishes it to be understood that his principal object has been to give a brief description of the method in use at the Wallsend Slipways, which are to be visited by the Members of the Institution on this occasion. But, before describing the system employed there, he proposes to refer shortly to two or three others, each of which possesses certain peculiarities of its own.

Armstrong's System.—This system is in use at the Howdon Yard of the Tyne Improvement Commissioners, and can be seen during this week by Members of the Institution.

It consists of one hydraulic cylinder A, Figs. 1 to 3, Plate 78, in which works a piston X, attached to a hollow ram B., Fig. 3. Inside this ram a second ram C is placed; and by the combination of these three different powers are obtained. For light loads pressure is admitted to the inside of the ram B only, forcing out the small ram C; for intermediate loads pressure is admitted to each side of the piston X, and a power is obtained due to the area of the large ram B. For heavier loads pressure is, in the same manner, admitted to the back of the piston; but the other side is opened to the exhaust, and thus the full value of the piston area is obtained.

The mode of hauling is as follows. A wrought-iron crosshead is attached to the end of the ram C, from which two short stud-link chains pass backwards to two barrels DD, keyed on a cross shaft behind the cylinder and having the end of the chain securely fastened to them. On this same shaft are placed two chain-wheels EE, running loose on the shaft, but which can be connected at will with

the chain barrels D by suitable clutch gear; round these chain-wheels are passed the chains J, leading down the slipway to the cradle. When the ram is forced out of the cylinder, the chain barrels D are made to revolve through an arc of a circle, due to the stroke of the ram, and carry with them through the same arc the chain-wheels E, round which the slipway chain J is wound; this chain, as it uncoils, drops into a pit behind. When this movement ceases, the vessel is held in position by three pawls on the pawl-wheel F, and remains stationary. The clutch which connects the wheels E with the barrels D is then withdrawn, and the drawback cylinder G coming into operation draws the ram back into the cylinder A, by causing the chain wheels D to revolve back again, through the same segment of a circle as that through which they had been made to revolve by the outward movement of the ram. The whole machinery is then in its original position, and the water being again admitted to the ram, the operation is repeated till the vessel is hauled up the slipway as far as required. The relief valve is operated by the tappet rod T, worked off the cross-head; and the empty cradle is hauled up and down the slipway by the chain K, shown at the side in Fig. 2.

2. *Hayward Tyler and Co.'s System.*—The system of haulage adopted in this case is shown in Figs. 6 and 7, Plate 79. As described in "Engineering," 11 May 1877, it consists of four hydraulic cylinders, laid parallel and in pairs, as shown. The rams of each pair are connected by a crosshead, through which the traction links A pass, and thence extend down the slipway to the cradle. On the top of each crosshead are bolted two standards B: through the upper end of each passes a horizontal shaft, with a hand-lever on the outer end. In the centre of this shaft is keyed a double segment C, one arm of which is weighted, while from the other is suspended an iron block D, which serves as a stopper, and is so placed as to drop, when the segment is depressed, between a pair of short links in the traction-rod. These pairs of short links E are placed at regular intervals corresponding with the stroke of the ram. The balance weight on the segment C holds up the stopper in the position shown on the right hand in Fig. 6, out of the way of the rods; but by

turning the lever on the end of the horizontal shaft, as shown on the left hand, the stopper is lowered into its place between the pair of short links, and against the crosshead which couples the pair of rams. The action of the machine is as follows. When the traction-rods have been connected to the cradle, and led up to the cylinders, the forward "stopper" is depressed into its position between the links, and the forward rams are put in motion, thus carrying forward the traction-rods and hauling the vessel up the slipway. Immediately before the travel of the first pair of rams is completed, the second stopper is lowered to engage between another pair of links, and the hinder rams are then set in motion, continuing the work. As soon as the strain is thus taken off the first stopper, it is raised clear of the links by the balance weight on the segment, and is lowered again only when the second pair of rams have nearly completed their stroke, the first rams having been meantime run back. Thus the work of hauling up the cradle proceeds continuously. The back travel of the rams is effected automatically by means of counter-weights, the water pressure being first relieved by the crosshead striking a stud which opens an outlet valve; or in some cases a small reversing cylinder is employed instead of a counter-weight.

This apparatus has been supplied by Messrs. Hayward Tyler and Co. to the Italian Government for the dockyard at Spezia, and to many other foreign ports. It seems to possess the advantage of avoiding the loss of time due to "fleeting" or interruption in the movement of the vessel, and to any retrogression of the cradle; but the first cost would apparently be very great.

3. *Day Summers and Co.'s System.*—This simple arrangement is employed by Messrs. Day Summers and Co. at Southampton, and is shown in Figs. 4 and 5, Plate 78. As described in "The Engineer," 12 September 1879, it consists of a drum B, 5 ft. 2 in. diameter, on which is wound a steel wire hawser A, 9 in. in girth, and which is driven by worm wheel and gearing connected with a small pair of engines, as shown. This drum is large enough to carry the whole length of the wire hawser without a second coil. To prevent any bruising of the strands of the steel wire against the iron drum, the

surface of the latter is covered with hard rope, tightly strained on the drum, and this protection is said to answer very well.

The spur wheel C upon the large drum B is worked by the pinion D, Fig. 5, which can slide in or out of gear with C, and when out of gear allows the small drum E to work independently of the large drum B, for the purpose of hauling up the empty cradle, and of unwinding the steel hawser A off the large drum. This is effected by taking two or three turns round the barrel E with a light chain, one end of which passes round a pulley at the lower end of the slipway, and is then brought back and made fast to the end of the wire hawser A. The drum E is then set in motion, and the light chain pulls the wire hawser off its drum and hauls it down to the cradle, where it is made fast, and is thus ready to haul up the next vessel.

As in this system there is no interruption in the onward movement of the vessel up the slipway—technically known as "fleeting,"—the work is done very rapidly; and as few hands are required, the cost is consequently small.

Thompson's System.—This system, designed by Mr. John Thompson of Newcastle, and Mr. T. B. Lightfoot, by whose firm the machinery was constructed, is now in use at the slipways of Messrs. Cleland and Co., and Messrs. Palmer's Shipbuilding Company, on the Tyne; at Penarth Docks; and at Messrs. Raylton Dixon and Co.'s Works, Middlesborough. It consists of a treble-powered hydraulic hauling apparatus, Figs. 8 and 9, Plate 80, placed at the top of the ways, and connected by means of suitable crosshead and rods to a double set of main traction links, which extend nearly to the bottom of the ways. The three powers are obtained by allowing the pressure (which may be taken either direct from a pump or from an accumulator) to act respectively on the centre ram alone, on the two outer rams, or on all three together. The rams are single-acting, and the water is admitted or exhausted by the attendant, controlling an ordinary hydraulic working valve. The return stroke is accomplished by means of a small single-acting hydraulic cylinder, on the ram R of which the pressure water constantly acts. The

connection to this ram R is in some cases made by chains, Fig. 10, attached to the extreme end of the links, and carried round suitable pulleys up to the returning cylinder, which is fixed above low water. In other cases, Fig. 11, the ram R is applied direct to the crosshead of the hauling cylinders, rods or chains being taken down the whole length of ways to the bottom end of the links, so as to transmit the proportion of power required for hauling them down the ways.

With this arrangement of machinery, the attendant, by simply working one lever forwards and backwards, can cause the links to travel up and down through a distance determined by the stroke of the rams, which is about 11 ft. Suitable pawls, attached to the main timbers of the cradle, gear with the connecting plates of the links, which are spaced exactly 10 ft. apart, so that at every upward stroke the cradle is hauled 10 ft. The usual pawls, rack, and centre rails prevent the cradle from returning with the links on the backward stroke. Several sets of pawls are used, so as to distribute the strain on the cradle. The empty cradle is hauled down either by separate hydraulic purchase with ordinary chain, or by a small ram applied within the centre hauling ram, the large rams being locked back during this process.

The machinery on this system erected at Raylton Dixon and Co.'s, and at Palmer's Works, is the same in principle as the above; but instead of three distinct hauling cylinders one only is used, fitted with two concentric rams, of which the larger and outer is used for heavy, and the inner for light loads. When the smaller ram alone is being used, the larger one, which is provided with a stuffing-box and gland for the other to work through, is locked back by two removable keys.

Wallsend System.

The system at the Wallsend Slipway does not claim any special novelty, but its chief peculiarity lies in the *length* of the slips, which measure 1000 ft. from the bottom end of the rails to the upper end of the hydraulic cylinder. The machinery was constructed by Messrs. S. and H. Morton and Co., of Leith, in the year 1873: but the system was first designed by the late Mr. Morton in the year 1819, and was carried into comparatively general use in

succeeding years. About the year 1832 a Select Committee of the House of Commons awarded Mr. Morton a considerable sum, for the great advantage his invention had been to the shipping interest of the country. The general arrangement of the slipway is shown in Figs. 12 to 14, Plate 81. The foundations are shown in the section Fig. 12, and consist mainly of slag. For the first year or two after the slipways were in operation, some settlement took place, and the longitudinal balks had to be wedged up from the cross-timbers; but of late no trouble has been experienced from this cause. The inclination of the slipways is $\frac{5}{8}$ in. to a foot, or 1 in 19.

Machinery.—As will be seen from Figs. 15 and 16, Plate 82, and Fig. 19, Plate 84, the cradle consists of a main body of timber framing, 173 ft. long, and extended by "ekes" E, along the centre of the slipway, to 284 ft. long. These "ekes" are balks of timber surrounding a wrought-iron bar, and running on wheels on the centre rail.

On the top of the longitudinal timbers, Fig. 19, Plate 84, which are supported by transverse balks resting on the slag foundation, are fixed cast-iron rails, Fig. 20, weighing 3 cwt. per running foot for the centre rails, and 1 cwt. per running foot for the outer rails: on the latter there run two extensions or continuations of the main cradle framing, and upon these rest the transverse wrought-iron arms A, Fig. 19, which support the sliding bilge-blocks B. The weight of the whole cradle, arms, &c., is about 160 tons. When a vessel is "relieved," as described hereafter, these arms swing on strong centre pins into a longitudinal position, and allow the cradle to be removed entirely from under the vessel. The motive power for each slipway consists of a hydraulic cylinder, the ram or plunger of which is 15 in. diameter and 10 ft. stroke, corresponding with the length of the traction links. Water is forced into the cylinder by three pumps, each $3\frac{1}{2}$ in. diam. and 12 in. stroke, making in quick gear 50 strokes per min., and in slow gear 25 strokes per min. The general arrangement is shown in Figs. 17 and 18, Plate 83. Attached to the outer end of the ram is a strong crosshead A, and connected to it are two wrought-iron rods, passing backwards outside the cylinder; these are

again joined together by a second crosshead B, to which the series of successive links C, leading down the slipway to the cradle, are attached. These links, shown enlarged in Figs. 21 and 22, Plate 84, are of wrought iron, each 10 ft. long from centre to centre of the eyes, and $3\frac{3}{4}$ in. diam., giving a sectional area of 11·04 sq. in. The pins are of steel of same diameter. The pumps, Figs. 17 and 18, are driven from the engine through the pinion D (which can be shifted in or out of gear as required), and one or other of the loose wheels E F, which can be connected to their shaft by a clutch. This same shaft also drives through the intermediate gearing G the chain sheave H. This sheave works an ordinary short-link chain, called the "back chain," which is used for pulling up the empty cradle after a vessel is launched; and also for pulling it down into its lowest position, to receive a vessel coming on for repairs.

Working with this machinery, the mode of operation is as follows. The cradle is run down into the water by its own weight, assisted occasionally by the back chain, which is sometimes rendered necessary by the accumulation of mud lying at the lower ends of the slipways, into which the cradle has to force its way; or again, in the case of large and long vessels, the lower end of the cradle is often pulled 40 or 50 ft. beyond the rails, and rests on the hard mud bank existing outside. The vessel to be taken on the cradle is then guided into an approximate position, by ropes carried to capstans on the jetties, Plate 81. Attached to the upper end of the cradle are two long iron rods I, Fig. 15, Plate 82, a few inches on each side of the centre line of the cradle, and each hinged at the lower end, so as to enable them to be raised from a horizontal to a vertical position: the outer ends of these rods are buoyed, and when the vessel is approximately in the proper position light ropes fastened to the rods are passed on board ship and hauled up tight. The iron rods, thus raised to a vertical position, form two guides between which the vessel can be accurately placed on the keel-blocks, guided by the controlling ropes on shore. The cradle is then hauled slowly up the ways by the hydraulic ram, till the stem grounds and settles on the foremost "eke," the stern being still afloat. Two similar rods to those described above are attached to the lower end of the cradle, and the stern of the ship is in like manner guided between them, till by the concurrent upward

movement of the cradle the whole length of the keel rests on the line of keel-blocks. The moment this operation is complete, the bilge-blocks B, sliding on the transverse arms A, Fig. 19, are hauled into position against the bilge of the vessel by ropes passed on to the nearest jetty, and when pulled home the ropes are passed on board the vessel and there made tight. The vessel is then safely and securely seated on the cradle.

The operation of hauling up now commences. The length of each traction link is 10 ft., corresponding with the stroke of the hydraulic ram, as before described. Each time the ram with its crosshead is forced by the pumps out of the cylinder, the cradle with its burden, and the connecting series of links, advance up the ways through the length of one link or 10 ft. The outlet valve of the cylinder is then opened, the water escapes, and the vessel falls back on to pawls attached to the underside of the cradle, which catch into teeth cast on the centre rail, Fig. 20. A counterbalance weight brings the ram back into the cylinder; the first link is removed by means of a small travelling crane, and a new attachment is made between the crosshead of the ram and the next link of the series. This process is repeated until the cradle and the vessel thereon are pulled clear of the water.

When a vessel is to be launched, the reverse process takes place. All the pawls, except one or two at the fore end of the cradle, are tied up; these two are worked by hand till the vessel is lowered far enough down the slipway to allow of launching, when these in turn are also tied up, and the vessel rests for a short time on one single pawl or "dagger." The lowest link is then disconnected from the fore end of the cradle, and the dagger being knocked away, the cradle with its burden runs down the ways. As deeper water is reached, the vessel floats away from the cradle. The back chain before alluded to is then connected to the chain sheave H, Fig. 18, at the head of the slipway, and by its means the empty cradle is pulled up the slipway till it is again required.

Speed of Working.—When the vessel is once fairly seated on the cradle, and the hauling up process can commence without interruption, the rate of movement is as follows:—

For light vessels in quick gear 2 min. per link or rod 10 ft. long.
„ heavy „ slow „ $3\frac{1}{2}$ „

Owing however to the time occupied in the successive removal of rods, the actual rate of progress up the slipway is not so fast, and is about as follows:—

Single rods, for light vessels in quick gear, $2\frac{1}{2}$ to 3 min. per rod.
„ heavier „ slow „ $4\frac{1}{2}$ to 5 „

When the size and weight of the vessel exceed a certain limit, a double tier of rods is laid, Fig. 21, Plate 84, connecting the crosshead of the hydraulic ram with a similar crosshead attached to the foremost eke. Hence, although when the vessel is actually moving the rate of progress remains as stated above, yet owing to the longer time occupied in the removal of the successive pairs of rods the total time is about as follows:—

Double rods, comparatively light vessels, quick gear, 5 min. per rod.
„ very heavy vessels, slow „ 6 to 7 „

The total distance traversed by the cradle from the point where it first receives its burden is about 420 ft.; and the time occupied may be taken as about two hours with single rods, and three and a half hours with double rods, exclusive of course of the time required to place the vessel on the cradle, which is usually about three-quarters of an hour.

Comparison with Dry Docks.—An impression exists in some quarters unfavourable to slipways, as compared with dry docks, on account of the supposed greater safety of the latter. As to this, the writer can state that 714 vessels have been taken on the Wallsend slipways from their opening in January 1874 to 30 June, 1881, a period of $6\frac{1}{2}$ years, and not a single accident of any kind has happened to any one vessel by reason of defect or insufficiency in the system employed.

The vessels in question have of course been of all sizes and tonnages. The heavest vessel yet attempted was H.M. Troopship "Tyne," measuring 320 ft. long × 34 ft. beam, gross registered

tonnage 2169 tons, displacement weight 1700 tons. She contained besides 300 tons of pig metal ballast, making a total weight hauled up of 2000 tons.

The slipway system has moreover the following manifest advantages.

(1.) The height of the vessel from the ground allows a free current of air under the bottom, which is thus quickly dried; by the time the dirt and adhering scale are removed, it is always perfectly dry, and ready to receive a new coat of paint.

(2.) In case of heavy repairs to the bottom of a vessel, this height gives ready access to the plates or frames which have to be removed and repaired; and the workman can act with much greater efficiency than in a dry dock, where the bottom of the vessel is only a foot or two above the floor.

(3.) The process of repairing is never interrupted by the hauling up of another vessel; whereas interruption constantly occurs in large dry docks, from the necessity of letting in the water to admit another vessel behind the first.

(4.) An advantage of obvious importance to the capitalist is that the cost of construction of slipways able to contain four vessels at one time, as is often the case with the two Wallsend slipways, is considerably less than the cost of a dry dock with its pumping appliances, capable of giving equal accommodation.

Relieving.—This last consideration leads very naturally to a description of the mode by which the upper portions of the slipways are made available, and which enables two vessels, each say 300 ft. long, to be "slipped" one behind the other on each slipway clear of the water.

It has been already stated that the slipways measure 1000 ft. long from end to end. When it is required to use the upper portion of the slipways, *e.g.*, when extensive repairs or alterations are in question, or when a vessel is to be lengthened, the cradle carrying the vessel is hauled, in the manner before described, right up to the top of the ways, leaving space for another vessel between it and high water. When in this position the operation of "relieving" is undertaken.

This is commenced by placing between each pair of transverse arms A, Fig. 19, Plate 84, (and in most cases also forward of the foremost arm) strong blocks of timber as bilge-blocks, capable eventually of carrying the whole weight of the vessel. Commencing just forward of the foremost arm, and simultaneously on the port and starboard, these new bilge-blocks are very tightly wedged against the bilge or underside of the vessel; the weight of the vessel is thus removed from the bilge-blocks B sliding on the arms A, and taken by the new bilge-blocks resting on the ground. The bilge-block on the first arm is then slid out from under the vessel, and the arm is free to be turned from a transverse into a longitudinal position. This process is continued till all the arms on each side of the vessel are free of it; and the ship now rests solely on the new bilge-blocks, and on the keel-blocks upon the cradle.

These latter are disconnected in their turn in the following way. Along the centre line of the cradle are a series of short hydraulic lifting presses PP, Plate 82, which are connected with the pumps used for the hydraulic cylinder by pipes laid beneath the surface of the ground. These being set going, water is forced into all these presses simultaneously, and the whole vessel is raised very slightly, but sufficiently to allow of the removal of the centre keel-blocks. When the pressure is relieved, the vessel sinks gradually back on to the new bilge-blocks just described. The whole cradle is now clear, and free of the superincumbent vessel. The cradle is then allowed to move down the slipway, and is ready to be used for the reception of other vessels for painting or slight repairs, till the heavier work upon the "relieved" vessel is completed. She is then placed again on the cradle by a process exactly the converse of that just described, and is lowered down the slipway for launching.

It will be seen that the relieved vessel rests entirely on the new bilge-blocks, which are further supported by side shores, and that under the line of the keel the slipway is perfectly clear, so that the rods required for the use of the cradle in its lower position can be run up or down without hindrance. Further, in the event of any one or more of the new bilge-blocks coming in the way of a damaged plate

that requires removal, this block can be readily removed and rebuilt, in any way rendered necessary by the work to be carried out.

Several vessels have been very readily lengthened on these slipways by this method. The fore body of the ship is relieved in the manner just described, leaving the after body resting on the cradle. The separation of the vessel into two portions is then made in the usual mode; and when this is complete the cradle is slowly lowered down the ways for a distance corresponding with the additional length which it is proposed to give to the vessel. The after body is then in its turn relieved, and the whole cradle removed from under it. The new part of the ship is then built, and when the whole is complete the vessel is replaced on the cradle and launched.

In conclusion the writer appends a Table showing the power actually required to haul up a number of vessels (of which he has been able to obtain the exact displacement weight), as ascertained by the registration of the gauge attached to the hydraulic cylinder, compared with the theoretical power required, as obtained by calculation.

The formulæ employed are seen to be simple, and the comparison of the "actual" with the "theoretical" power is interesting. It will of course be at once evident that the excess of the former over the latter is caused by variations of weather, inequalities of the slipway, more or less perfect lubrication, and the many other conditions of actual working.

APPENDIX.

Theoretical Calculation of Power Required to move Vessels up Slipway.

Power required for Weight (Formula A).—The formula here is :—Power = R $\times$ slope of incline = R $\times \frac{1}{19}$, where R is the total weight, which in the case of the vessel No. 22 is made up as follows :—

Weight of Vessel =	1500	tons
Weight of Cradle =	160	„
Weight of Links =	13	„
Total Weight	1673	„

Hence Power for Weight $= \frac{1673}{19} = 88$ tons.

Power required for Friction of Cradle, &c. (Formula B).—Here the formula is :—

$$\text{Power} = \frac{\text{coeff. of friction on axles} \times \text{diam. of axle} \times \text{weight of vessel and cradle}}{\text{Diameter of wheel}}$$

For No. 22, Power for Cradle Friction $= \frac{0 \cdot 2 \times 2 \cdot 5 \text{ in.} \times 1660 \text{ tons}}{10 \text{ in.}}$

$= 83$ tons.

Power required for Friction on Leather Collar of Ram (Formula C). Here the formula is :—

Total pressure = pressure per sq. in. $\times$ depth $\times$ circumf. of collar
= 2800 lbs. (in case of No. 22) $\times$ 1 in. $\times$ 47·5 in.
= 59 tons.

Power = Total pressure $\times$ coefficient of leather on iron in motion *
= 59 tons $\times$ 0·56
= 33 tons.

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* Leather on iron in repose gives coefficient of friction 0·80,
„ „ in motion „ „ 0·80 $\times$ 0·70 = 0·56.

Power in Tons required to Haul up Vessels.

Number of Vessel.	Gross Register Tonnage.	By Calculation.					By Gauge.	
		Actual Weight of Ship.	Power for Weight.	Power for Friction of Cradle.	Power for Friction of Collar.	Total Calculated Power.	First time on Slip.	Second time on Slip.
			Formula A	Formula B	Formula C			
		Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
1	932	630	42·26	39·5	18	99·7	120	120
2	902	650	43·4	40·5	19	103	125	
3	866	670	44·4	41·5	20	107	130	140
4	971	800	51·2	48·0	21·8	121	145	
5	1374	820	52·3	49·0	21·8	124	145	140
6	1531	920	57·5	54·0	21·4	133	140	150
7	1261	920	57·5	54	22·8	134	150	160
8	1323	920	57·5	54	22·8	134	150	
9	1250	930	58	54·5	22·8	135	150	
10	961	1000	61·7	58	30	149·7	200	
11	1613	1010	62·2	58·5	27·5	148	180	
12	1469	1030	63·3	59·5	28·7	151·5	190	
13	1571	1040	64	60	22·8	146·8	150	180
14	1568	1040	64	60	24·2	148	160	
15	1727	1040	64	60	25·3	149	170	170
16	1498	1070	65·4	61·5	22·8	149·7	150	180
17	1683	1220	73·3	69	31·7	175	210	
18	1646	1220	73·3	69	33	175	220	
19	1913	1340	79·6	75	31·7	186	210	
20	1879	1340	79·6	75	30	184·6	200	
21	1873	1350	80	75·5	30	185·5	200	
22	2141	1500	88	83	33	204	220	

EXCURSIONS, &c.

The following Works, &c., in Newcastle and Sunderland, and in their neighbourhood, were thrown open to the members in the course of the week:—

Sir W. G. Armstrong and Co.	Engineering and Ordnance Works.
Robert Stephenson and Co.	Engineering Works.
R. and W. Hawthorn	Ditto.
J. and G. Joicey	Ditto.
Donkin and Nichol	Ditto.
Walkers, Parker, Walker, and Co.	Lead Works.
M. and M. W. Lambert	Printing and Bookbinding.
Andrew Reid	Printing, Engraving, &c.
Newcastle Chronicle Office	Newspaper Printing.
T. and W. Smith	Hemp and Wire Rope Works.
Henry Angus and Co.	Coachbuilding Works.
Atkinson and Philipson	Ditto.
North Eastern Railway Works	Engineering Works.
John Abbot and Co.	Iron and Engineering Works.
R. S. Newall	Wire Rope Works.
Haggie Brothers	Hemp and Wire Rope Works.
Black, Hawthorn, and Co.	Engineering Works.
Clarke, Chapman, and Gurney	Ditto.
Hawks, Crawshay, and Sons	Iron and Engineering Works.
Newcastle Chemical Works Co.	Chemical Works.
Tyne Improvement Commissioners	Newcastle Swing Bridge.
" " "	Howdon Repairing Shops and Slip-ways.
" " "	Coble Dene Dock (under construction).
" " "	South Shields, South Pier (under construction).
" " "	Tynemouth, North Pier (under construction).
J. T. Eltringham	Engineering Works.
Jarrow Chemical Co.	Chemical Works.

John Readhead and Co.	Shipbuilding and Engineering Works.
J. P. Rennoldson	Engineering Works.
Hepple and Co.	Ditto.
Andrew Leslie and Co..	Shipbuilding Works.
Charles Tennant and Co.	Chemical Works.
Foster, Blackett, and Wilson . . .	Lead Works.
Palmer's Shipbuilding Co.. . . .	Shipbuilding, Engineering, and Iron Works.
Swan and Hunter	Shipbuilding Works.
Schlesinger, Davis, and Co. . . .	Ditto.
Wallsend Slipway and Engineering Co.	Engineering and Ship Repairing Works.
C. Mitchell and Co..	Shipbuilding Works.
Wigham Richardson and Co. . . .	Shipbuilding and Engineering Works.
Tyne Iron Shipbuilding Co. . . .	Shipbuilding Works.
Cookson and Co.	Lead Works.
Tharsis Copper Co..	Copper Works.
John Spencer and Sons	Steel Works.
Robert Thompson and Sons . . .	Shipbuilding Works.
J. L. Thompson and Sons	Ditto.
James Laing.	Ditto.
George Clark	Engine Works.
Armstrong, Addison, and Co. . . .	Timber Preserving Works.
William Doxford and Sons. . . .	Shipbuilding and Engineering Works.
John Blumer and Co.	Shipbuilding Works.
S. P. Austin and Son	Shipbuilding and Repairing Works.
Strand Slipway Co..	Shipbuilding Works.
Short Brothers	Ditto.
Osbourne, Graham, and Co. . . .	Ditto.
Bartram, Haswell, and Co.. . . .	Ditto.
John Dickinson	Marine Engine Works.
C. H. Reed and Co..	Forge, Chain, and Anchor Works.
S. Tyzack and Co.	Iron Works and Rolling Mills.
J. and E. Lumsdon	Forge, Chain, and Anchor Works.
Ford Paper Works.	
Hendon Paper Works.	
Southwick Pottery.	
Sunderland Gas Works.	
Sunderland and South Shields Water Works.	
Weardale Iron and Coal Co. . . .	Rolling Mills.
Consett Iron Co..	Ditto.

On the afternoon of Tuesday, 2nd August, the Members were entertained at luncheon by the Local Committee, at the Assembly Rooms. They were then conveyed by special train to Elswick, to visit the works of Sir W. G. Armstrong & Co. The party were received by Sir William Armstrong, Mr. George Rendel, and Mr. Percy Westmacott, and were conducted over the works. The party then divided, one section going on by special train to visit the Newburn Steel Works of Messrs. John Spencer and Sons, and the other returning by special steamer to inspect the Swing Bridge at Newcastle, the opening and closing of which were exhibited. For a description of the bridge see notice below of the Elswick Works. At Newburn the party were received and entertained by Mr. John W. Spencer, and went over the whole of the works.

In the evening the Members were splendidly entertained by Sir W. G. Armstrong, Past-President, in the Banqueting Hall, Jesmond Dene.

ELSWICK ENGINE AND ORDNANCE WORKS, NEWCASTLE-ON-TYNE.

N.B. The following notice of these works is mainly condensed from articles in *The Engineer*, July 1881, reprints of which, presented by the kindness of the proprietors, were distributed to the Members at the time of the visit.

The Elswick Engine Works, started in 1847, owe their origin to Sir William Armstrong's success in the development of water-pressure machinery; similarly the manufacture of ordnance grew up in consequence of his having brought out his system of ordnance. The former branch of the works preceded the latter by about ten years, and therefore should be first noticed.

The hydraulic machinery* manufactured at the Elswick Works consists chiefly of cranes, hoists, capstans for railway stations and docks, rotary engines, pumping engines, opening bridges—swing, draw, and lift—machinery for opening and closing dock gates and sluices, bands and elevators for discharging and storing grain, hydraulic pumps, winding engines for mines, &c. &c. In addition

* For papers dealing with this machinery see Proceedings 1858, 1868, 1869, 1874.

to these there are the steam pumping engines, with boilers and accumulators, for supplying the water under pressure.

The ordinary forms of hydraulic cranes and hoists, as used in docks, railway stations, warehouses, &c., are so well known that any detailed description of the several varieties is unnecessary. In nearly all cases where the lifting power does not exceed 30 tons, the hoisting apparatus consists of a cylinder and plunger acting on the lifting chain through a system of fixed and moveable pulleys, which multiply the travel of the plunger to the extent required. By this means the necessity for any gearing, brakes, pawls, and clutches is avoided, and the working of the crane is rendered very simple and safe. The lifting machinery is usually placed in the revolving pillar of the crane itself, so as to economise space and cost of foundations. For dock purposes the crane is usually mounted on a pedestal of wrought iron about 8 ft. or 10 ft. high, so as to give the jib clearance over a ship's side ; and this pedestal is provided with wheels, so that four or five cranes can be brought to bear upon the several hatchways of one vessel. These cranes are either counterweighted or clamped to the rails when at work, as may be most convenient. The connections to the pressure and return mains are made by sliding or jointed pipes, attached to hydrants inserted at intervals in the main pipes.

When a lifting power of from 30 tons to 80 or 100 tons is required, a rotary hydraulic engine, acting on an ordinary chain purchase by means of gearing and a "cupped-drum," is usually employed, and the general construction of the crane is modified by a circular roller path with live or fixed rollers being substituted for the iron pedestal. For very heavy cranes, to lift loads of 80 tons to 100 tons and upwards, Sir W. G. Armstrong and Co. now use a direct-acting cylinder of from 40 ft. to 54 ft. stroke, suspended in gimbals from the end of the jib, and fitted with a piston and rod, by which the load is lifted and lowered without the intervention of chains or gearing. These cranes are on "live" rollers, and are turned by a rotary hydraulic engine acting on a rack attached to the roller path. An independent chain purchase, worked by the slewing engines, is provided for lifting loads up to 12 or 14 tons.

Hoists for shipping coal are much made at Elswick, for South Wales and other ports where the railways approach the docks at a low level. The lifting cylinders are usually direct-acting, and, with a view to economy in the consumption of power, are so arranged that on the down stroke the weight of the cradle and empty truck is made use of, to force back the water from one of the cylinders into the accumulator.

Hydraulic capstans are very much used, not only for docks, but also for hauling trucks in railway goods stations, and in connection with coal hoists. The bed-plate carrying the capstan-head and engine is mounted in trunnions in a cast-iron casing, and can be turned over when access is required to the engine. The casing is bedded in the ground, and scarcely any foundation is required. Sir W. G. Armstrong and Co. are now introducing a new pattern of engine for this class of work, which acts directly on the capstan-shaft, and is fitted with a valve common to the three cylinders.

Swing bridges may be divided into two classes—one in which the bridge is lifted bodily from its bearings by a hydraulic press before being swung round, and the other in which the bridge is permanently on rollers, either fixed or "live." The combined road and railway bridge erected by Sir W. G. Armstrong & Co. over the 100 ft. entrance to the Queen's Dock at Glasgow, under the direction of Mr. Deas, the engineer to the Clyde Trust, is a good example of the first class. There are two main girders, curved on the top, each 181 ft. long, and 25 ft. deep over the centre of motion. The width between the main girders is 23 ft. 6 in., and there is a cantilever footway 5 ft. 3 in. wide on each side. The hydraulic press is 5 ft. 3 in. diameter, and acts on a transverse box girder, riveted to the underside of the main girders. The bridge is turned by a pair of hydraulic cylinders, acting through chains on a drum fixed to the underside of the bridge. This bridge is designed for very heavy road and railway traffic, and the total weight of the moving parts, including counterweight, is about 750 tons.

The swing bridge over the Tyne at Newcastle may be taken as an example of the second class, namely that in which the bridge is permanently on its bearings. This bridge is for road traffic, and when

open leaves two passages each 100 ft. wide, one on either side of the centre. The main girders are each 277 ft. long and 24 ft. deep at the centre. The roadway is paved with wood, and has a clear width of 23 ft. 9 in. There are in addition cantilever footways 9 ft. wide outside each main girder. The bridge turns on forty-two "live" rollers of cast-iron hooped with steel. The roller paths are of cast-iron, the lower being bedded on the masonry of the central pier, and the upper bolted to an annular box girder on the underside of the main girders. The total weight of the moving parts of the bridge is about 1400 tons; and in order to diminish the pressure on the rollers a hydraulic press is provided at the centre of motion, which exerts a constant upward pressure of about 800 tons, thus relieving the rollers to this extent. The turning machinery is entirely in duplicate, and is on the central pier. There are two steam pumping-engines, each of 20 horse-power, two multitubular boilers, and two accumulators, which are placed in two of the foundation cylinders. There are two hydraulic rotary engines, each of 60 horse-power, acting through gear on a rack bolted to the upper roller path. The teeth of this rack are 13 in. wide and 9 in. pitch. The apparatus for setting up the nose ends of the bridge is worked by hydraulic power, and consists of two pairs of hydraulic presses with rams acting downwards on the abutments, and the same number of horizontal sliding blocks. When the nose ends of the bridge are over the abutments, the girders are slightly lifted, and the sliding blocks inserted between them and the resting plates on the abutments. The water is then exhausted from the presses, and the ends of the girders rest on the blocks. The valve house, from which all the motions of turning &c. are controlled, is placed on the overhead platform, which connects the main girders. Above this house is a dioptric light of the 7th order. The bridge is approached by two fixed spans, of 99 ft. and 80 ft. respectively. This work was carried out under the direction of the engineers to the Tyne Commission, Mr. J. F. Ure and Mr. P. J. Messent.

Another variety of the opening bridge is the drawbridge, or rolling bridge, which is used where the site is not suited for a turning bridge. The operation of opening one of these bridges consists in lifting it from its bearings until the underside is above the level of

the roadway or quay, and then running it back on the roadway. The bridge is lifted by a pair of hydraulic presses near the quay edge, one under each main girder. The rams of these presses are furnished with rollers, on which, and on other fixed rollers at the rear end, the bridge is run back, a suitable roller path being fixed to the underside of the main girders. The bridge is run in and out by a pair of hydraulic cylinders. Sir W. G. Armstrong & Co. are now erecting a bridge of this class, with a span of 90 ft., over the entrance to the Kattendyk Basin at Antwerp. The length of this bridge, which is designed for both road and railway traffic, is 159 ft., and the width 30 ft. over all. There are two main girders, each 9 ft. deep. The total weight of the moving parts, including counterweight, is about 350 tons. The lifting presses are each $31\frac{5}{16}$ in. diameter, and 3 ft. 2 in. stroke, and are hooped with steel. The rollers are 3 ft. 6 in. diameter, and 9 in. wide, and are also hooped with steel, and the roller path on the bridge is of the same material. The hauling cylinders are placed below the rear end of the bridge.

For opening and closing dock gates, four forms of apparatus are commonly used. The first consists of a cylinder fixed at the back of the wall below the quay level, and fitted with a plunger and multiplying sheaves as in a crane or hoist, the chain being attached at one end to the cylinder and at the other to the gate. Two such cylinders are required for each gate, one to open and the other to close. In the second form the chains are passed over a crab provided either with an ordinary barrel or with a cupped drum, and driven by a rotary hydraulic engine. At the new Langton Docks, under the direction of Mr. Lyster, the machines for closing the gates have been furnished with spiral drums, so as to take up the slack chain quickly and without waste of power. The third form is a modification of that last described. The chains, instead of being fixed to the gates, are attached to the lock walls, and pass over guide sheaves on the gates and above the heel-posts to the crab, which is placed in a chamber in the quay as near the heel-post as convenient. By this device the crabs for the opening and closing chains can be placed side by side and worked by one hydraulic engine. The necessity for chainways through the walls is also avoided, and the foundation work

is much simplified. In the fourth form the gate machines and capstans are connected by shafting, or two or more gates and capstans are driven by one hydraulic engine.

The simplest and best form of hydraulic machine for opening and closing sluices is a cylinder fixed vertically over the paddle or sluice-door, and fitted with a piston and a piston-rod or plunger attached to the paddle. A hand force pump, either fixed or movable, is usually provided, for working the sluice by hand when required. In some cases a screw is used instead of a hydraulic cylinder, the nut being driven by a hydraulic engine.

The steam pumping engines which supply the water under pressure for working hydraulic machinery are for the most part horizontal, and the pumps are in the same line with the cylinders, and worked directly from the steam pistons, the piston-rods being prolonged backwards. Condensers, either jet or surface, are usually supplied with the larger engines, which are often constructed on the compound principle. An air vessel is sometimes substituted for a weighted accumulator. This plan was adopted in the case of the machinery for some hopper barges on the Tyne, the first of which was constructed in the year 1865, and has subsequently been carried out in several cases ashore and afloat.

The Ordnance Works are now to be described. In the original system of ordnance, introduced by Sir William Armstrong about 1858, the chief features were rifling, breech loading, and the application of coils shrunk over each other systematically. In the ordinary gun now constructed at Elswick this system of construction is still adhered to. At a later date however muzzle-loading came into favour, and muzzle-loaders are also constructed at Elswick, the coil system being retained. In February, 1878, a new type 6-in. gun of 78 cwt. was issued from Elswick, which was fired with charges about half the weight of the shot, giving to a projectile weighing 70 lb. a velocity of nearly 2200 ft. per second. In January, 1879, 8-in. muzzle-loading and breech-loading new type guns were submitted to the Government for trial. The great development of power in these guns is due to increased length, slow-burning charges,

and a specified allowance of air space in the powder chamber. In July, 1878, an Elswick new type 8-in. gun of $11\frac{1}{2}$ tons fired a 180-lb. projectile with over 2200 ft. velocity. This increase in length in ordnance is favourable to breech-loading, and in certain cases it would appear that breech-loading will enable guns of greater power to be employed than was possible with muzzle-loaders. The case of broadside guns for ships is a case in point. The breech-closing arrangement employed at Elswick is that now adopted in the British service.

The newest and most interesting gun constructed at Elswick is made almost wholly of steel, consisting of an inner steel tube, on which are wound coils of steel riband, with the tension on each concentric layer adjusted to agree with the results obtained by calculation. This is done by means of a machine designed for the purpose. The advantage of the riband gun is threefold—(1) that steel may be obtained in small section with greater strength than is possible in any other form; (2) that each layer can be brought more truly to its correct tension; (3) that the danger due to the existence of flaws becomes reduced to a minimum, because a flaw would be easily detected, and, if not detected, would be confined to the riband in which it existed. To give longitudinal strength, a certain number of layers are formed by short lengths of steel riband placed longitudinally like the staves of a barrel, and secured by doubling or hooking in the ends. The whole is cased with thin steel; one or two wrought-iron coils only are used on the entire gun. A 6-in. gun has been made on this system and fired, and it has given results far surpassing any that have yet been obtained with guns of the same weight; a 10-in. gun is nearly complete.

For some time after the introduction of rifled ordnance, very little improvement was attempted in carriages. In 1865 however iron carriages came in, and the Elswick Works turned out some early patterns. One pattern of disappearing carriage, differing from that of Moncrieff, and acting by hydraulic power, was designed at Elswick, and supplied to H.M.S. *Téméraire.* The application of hydraulic machinery to replace hand power has been specially advocated at Elswick, and is adopted there whenever it is possible. A special

arrangement is also in use by which muzzle-loading guns, mounted to fire *en barbette*, may be loaded under cover. This is effected by running the gun round on its traversing platform until it is parallel to the parapet, when its muzzle is dipped so as to bring it in line with a rammer in a fixed position, with charge and projectile presented ready for loading; and the gun, thus depressed, forms an incline, up which they are easily pushed home. The traversing platform rests on three points, not four: namely the two trucks, and a cap pivoting on the centre of the training circle. The gain is very great, for while a bearing on four points is constantly disturbed by the want of truth in the planes which contain the four points, a bearing on three points is always true.

The Elswick 100-ton muzzle-loading gun, as mounted for Malta and Gibraltar, is the largest example of a muzzle-loading gun firing *en barbette* on this system. The principle of keeping the centre of gravity of the mass nearly over the traversing centre is observed, while the employment of the gun as an inclined plane for running the shot up to its seat in the bore is applied to considerable purpose in the case of a projectile weighing 2000 lbs. The accumulator and engine are below ground. The accumulator is weighted to a pressure of 75 lbs. per sq. in., and is worked by an ordinary steam sapper of 6 horse-power. It can also be pumped up by forty men with hand-pump gear, in which case it is calculated that the gun can be fired at the rate of one round in about $7\frac{1}{2}$ minutes.

One other design should be mentioned, namely a mountain gun unscrewing into two parts at the trunnion ring. This device enables a field gun of considerable power to act as a mountain gun, instead of the short feeble weapon previously used. These guns have abundantly proved their value in Affghanistan.

The Elswick Works cover an area of ground lying between the river Tyne and the Newcastle and Carlisle Railway. The east end is devoted chiefly to ordnance work, the west end being the so-called engine works, where the engineering structures and hydraulic machinery are made. The offices are between these two departments, and the principal road and jetty are near the middle point.

Commencing with the Ordnance Works, at the N.E. corner, the first objects of interest are the 6-in. and 40-ton breech-loading guns, mounted to illustrate the "protected barbette" system of working guns, and also the system of working breech-loading guns in turrets by hydraulic power. Close to these guns is a shrinking-pit for ordnance; also nineteen gas-producers for furnaces. The shops may then be taken in the following order. *Coiling Shop*:—The largest section of bar coiled has been 12 in. by 10 in.; length of coiling furnace, 180 ft.; there is a gas furnace for heating barrels, also for tempering, with an oil well 50 ft. deep, over which stands a hydraulic hoist. *Forge*:—The largest hammer, by Thwaites and Carbutt, Bradford, has a 48 in. cylinder and 12 ft. stroke; weight of piston and hammer head, 35 tons. *Blast Furnaces*:—One furnace building, two in work, and running from 1100 to 1200 tons a week, chiefly Nos. 1, 2, and 3 pig, made from Spanish and Elba ores; most of it is sold for steel making. The blast is at present heated by horse-shoe pipes, but Cowper's heating stoves are in course of erection; present temperature of blast about 900° Fahr. *Carriage Shed*:—Band saws cutting iron may be noticed, and the Albini carriage on short-recoil and self-running-up system. *Projectile Store*, containing finished projectiles:—These are chiefly made with bands only of the full diameter, which saves work and leaves to the projectile body the strength of the uninjured skin of the casting. The Palliser chilled projectiles have generally sharp-pointed heads, struck with a radius of two diameters. *Foundry*, containing ten cupola furnaces, of which four are generally in work:—Forty tons is about the maximum weight of casting made in the foundry; a much larger casting, namely the bed of the steam hammer, weighing 137 tons, was cast on its own ground. The hydraulic cranes are fixed so as to work in pairs or three together for heavy work. *Engines*:—Horizontal double Corliss engines are generally employed, with multitubular boilers. Juckes's bars and system of stoking are applied to all. *Jetty*:—On the east end are two fixed hydraulic cranes for lifting 5 tons and 30 cwt.; and between them are large hydraulic shears, worked by a direct-acting hydraulic cylinder, 40-ft. stroke, lifting 120 tons. The back leg moves so as to bring the lifting cylinder

about 30 ft. beyond the face of the quay. The foot is moved by a screw 50 ft. long, with hydraulic engine and gear, giving three different powers. Along the jetty run pipes with hydrants from 18 ft. to 36 ft. apart, from which work five movable cranes, each lifting about 30 cwt.: these are placed in position to suit the holds of the vessels by means of telescope tubes attached to the nearest hydrants. *Finishing Shop*:—The new type guns should be noticed, together with the breech-loading fittings, and apparatus for firing by electricity and also mechanically. *Turning Shop*, for turning, finishing, and boring work, commencing on the solid ingot:—At the east end guns are bored vertically in a pit 23 ft. deep. *Large Tool Shop*, for turning, boring, and rifling:—The finest lathe is one of Whitworth's, for turning, boring, screw-cutting, and rifling, taking a job 44 ft. in length, 36 in. centres. There is also a convenient one, designed at Elswick, and made by Fairbairn Kennedy and Naylor, taking a chuck job 20 ft. in diameter and 4 ft. 6 in. long, or a job 34 ft. long and 8 ft. in diameter; it is fitted with slide-rests on independent beds. *Forge*:—Crank-shaft and gun work, coil welding, &c., are performed. The steam hammers are from 24 tons to 15 cwt. *Small Tool Shop*, turning and boring out short coils:—There is a large endless band saw $1\frac{3}{4}$ in. wide, which cuts directly through iron cylindrical work about 16 in. in diameter. Its speed is from 76 ft. to 129 ft. per minute.

In the Engine Works the shops may be taken in the following order. *Bridge and Boiler Yard*:—Contains plate-planing, punching, and multiple and radial drilling machines, &c. The work turned out is chiefly crane work and other structural ironwork. such as lighthouses, bridges, dock-gates, pedestals of cranes, &c. *Blacksmiths' Shop*:—Boiler and riveting work, &c., is done here. At the back of the building is the chain-making shop, where all chains for the firm are made, and tested by a hydraulic machine. Two Corliss horizontal engines, working to 190 horse-power each, with boilers and Juckes's grates, &c., are fixed here, and supply power to the whole engine works. *Fitting and Machine Shop*:—The east end of this was the first shop erected at Elswick; planing, boring, drilling, and turning are done here. The west end is used for erecting hydraulic machinery. There is a hydraulic testing machine for testing cylinders and valves

up to 3000 lbs. per sq. in. Behind this is the brass foundry. Phosphor-bronze is chiefly employed for gun-carriage work; its cost is considerable, but it works well without lubrication. *Pattern Shop*:—In this may be seen working a Richards planing machine, and also circular saws with adjustable spindles, with guide and graduated arc for setting work at any required angle. The sawn surfaces are so smooth as to enable planing to be dispensed with. *Erecting Shop*, for engines, large cranes, accumulators, &c.

There is a jetty adjoining these works, with 12-ton and 5-ton hydraulic cranes. The works yard is furnished with hydraulic capstans and snatch heads for hauling wagons about the yard, and other appliances. There are five pumping stations with accumulators, supplying hydraulic power throughout the works, at a pressure of about 700 lbs. per sq. in.

NEWBURN STEEL WORKS.

The firm of Messrs. John Spencer and Sons was established in 1810 by the late Mr. John Spencer, for the manufacture of files. A converting furnace and a mill for rolling steel were erected in the valley at Newburn, where water power was convenient. The water did duty first at the rolling mill, and again lower down on a large breastwheel, 30 ft. diameter, which is still in use for file-grinding. Furnaces for melting the blister steel on Huntsman's plan were also constructed. For several years files, bar-steel, and best tool-steel were the only manufactures carried on.

On the advent of the locomotive, and the establishment of works for its manufacture, and for that of railway material, the making of springs was commenced here; and for some time the earliest requirements in this line were supplied from these works, which were gradually enlarged to meet the increasing demands of railways. Baillie's volute spring was taken up, and was solely manufactured here for many years in large numbers. The Uchatius process for the manufacture of steel direct from pig-iron by fine granulation in water was tried on a practical scale, and a fine quality of steel was obtained (see Proceedings 1858, p. 146); but its irregularity

precluded its adoption at the time. The manufacture of steel tyres was introduced, casting them in a ring and hammering them on a bick iron; but it was discontinued because of the difficulty then experienced in rolling them. Casting steel in form was commenced here on a large scale in 1866, though for many years previously simple forms had been cast. Messrs. Spencer at that date turned their special attention to this branch of steel manufacture, and they now turn out upwards of 1000 tons per annum of gearing and general castings of steel, in form.

There are three open-hearth furnaces for the manufacture of steel by the Siemens and Siemens-Martin processes, capable of turning out 180 tons per week; two Siemens regenerative crucible-furnaces, each containing 24 pots, besides coke holes, for the manufacture of the finer kinds of steel. There are also eight converting furnaces for the conversion of Swedish bar iron into steel by cementation, their capacity ranging from 15 to 25 tons per heat.

The steel moulding shop is fitted up with hydraulic swing-cranes and overhead travelling cranes, for moulding purposes and for the general requirements of the shop; it covers an area of upwards of 1640 square yards. The forges contain three double-acting steam hammers by Thwaites and Carbutt, of 8 tons, 5 tons, and 2 tons weight, all served by hydraulic cranes and Siemens regenerative furnaces. In the steel tilting-forge are three steam hammers from 30 cwt. downwards. In the iron forge are a Naylor 30-cwt. steam hammer, and one of 15 cwt. by Thwaites and Carbutt. The new mill comprises an 18-in. and a 14-in. train, driven by a Corliss engine; and the old mill contains a 10-in. train and guides, worked by an old engine of locomotive type, by R. and W. Hawthorn.

The manufactures chiefly carried on are steel forgings, steel castings, and bar steel; also various kinds of railway material, such as axles, buffers, springs, and volutes; and files, tool steel, &c. The several shops are built along the valley and on various levels, but are all connected by a railway with one another, and with the Scotswood Newburn and Wylam Railway. A tank engine by R. and W. Hawthorn, and a very useful crane engine by Black Hawthorn and Co., make the transport of material comparatively easy, considering the position and extent of the works.

At Lemington, about one mile nearer Newcastle, are the Tyne Hæmatite Iron Works belonging to Messrs. Spencer, the oldest ironworks in the North of England; comprising two blast-furnaces, at present out of blast. There is here an old beam engine by Boulton and Watt, dated 1802, which was used for driving a mill and forge. Its beam, showing several imperfections and flaws, was originally considered unsafe, and a spare beam was sent to replace it; however the faulty one stood the work, and is still in its place. Here were made most of the castings for the permanent way and rolling stock used in the early railway trials of Hedley and Stephenson; and several old patterns still exist, which were shown at Newburn on the occasion of the visit of the Members.

On the afternoon of Wednesday, 3rd August, the Members visited the offices of the *Newcastle Daily Chronicle*, through which they were conducted by Mr. Jameson and Mr. R. B. Reed, and witnessed in operation the whole of the machinery and processes described in Mr. Jameson's paper, *ante* p. 511. Copies of the *Chronicle*, containing an account of that morning's meeting, were printed off by the Hoe machine, and distributed to the Members.

They then travelled by special train from Newcastle to Jarrow, to visit the works of Palmer's Shipbuilding and Iron Co. The party were received by Mr. C. M. Palmer, M.P., Mr. John Price the General Manager, and the other chief officials, and were most handsomely entertained at luncheon by the Company. They were afterwards divided into several sections and taken through the works, and at 5 p.m. returned by special train to Newcastle.

In the evening the Annual Summer Dinner of the Institution was held in the Assembly Rooms, the President in the chair, and was attended by over 200 Members and guests.

PALMER'S SHIPBUILDING AND IRON WORKS.

These works, situated at Jarrow, about six miles below the Tyne Bridge, include within themselves the entire range of operations from the smelting of the ironstone to the complete equipment of iron vessels. The ore itself is brought round by sea from the Company's mines at Port Mulgrave, near Whitby; and is raised from the river wharf at the works up to the railway level, along an inclined plane worked by a stationary engine. Coke and coal come from Marley Hill and other collieries in Durham and Northumberland, by the Pontop and Jarrow Railway; the coke is discharged into a hopper capable of holding about 1500 tons, from the bottom of which the blast-furnace barrows are filled through sliding doors, dispensing with manual labour. The three blast-furnaces are 85 ft. high, 24 ft. diameter at the boshes, and $8\frac{1}{2}$ ft. in the hearth; they are capable of producing together about 1400 tons of pig per week, more than three-fourths of which is used in the works. The blast is heated to about 1100° Fahr. in fifteen cast-iron pipe-stoves; and there are eight kilns for calcining the Cleveland ironstone.

The forges comprise eighty puddling furnaces, producing over 1000 tons of puddled bars weekly. There are two forge engines with 36-in. cylinders, one of 4 ft. and the other of 5 ft. stroke, each driving a roll train and four pairs of 22-in. rolls. There are two plate-mills and ten mill furnaces, producing about 750 tons of finished boiler and ship plates weekly; each mill has two pairs of 24-in. rolls, reversed by clutch and crabs. A bar mill with two pairs of rolls, driven by a 24-in. cylinder, produces 120 tons per week. A fourth mill, with four pairs of rolls, driven by two 30-in. cylinders with 4 ft. stroke, produces about 300 tons of plates per week. There is also a large angle and bar mill, driven by a single engine having 36-in. cylinder and 4 ft. stroke, capable of rolling the very largest angles used in the trade; and also a sheet mill. Attached to the rolling mills are shears, circular saws, punching and straightening presses, and other appliances for the construction of iron ships.

The adjoining department is that of the engine works, which is capable of finishing annually from 30 to 40 pairs of marine engines

with their boilers; this department produces its own iron and brass castings, and its own forgings. In the boiler shop, vertical rolls for rolling long boiler shell-plates were first used, and the original set are still in operation.

The shipbuilding department occupies the east end of the works; it contains the largest graving dock on the coast, and also a very fine repairing slip, just newly fitted with hydraulic hauling gear. The building slips are suitable for every kind of vessel up to 500 ft. in length; and are capable, with those in the Howdon branch of the works on the opposite side of the river, of launching 50,000 tons of shipping annually. There are nine building slips at Jarrow and four at Howdon.

The entire works cover more than 100 acres, with a river frontage of about 4,000 ft., and employ about 7,000 persons.

On Thursday, 4th August, the Members were again entertained at luncheon by the General Committee, and afterwards started from the Quayside in three special steamers, on an excursion down the Tyne. They first stopped at Bill Point, to watch the operations of a double dredger, working, not in mud or clay, but in sandstone rock. This dredger is of the ordinary type, but the ladders are fitted at intervals with heavy steel claws, which catch hold of the rock and break it off. Pieces weighing more than 10 cwts. are frequently brought up on the claws and in the buckets, and the amount raised is 500 tons per day. The Members then visited the Lead Works of Messrs. Cookson and Co., and the works of the Wallsend Slipway and Engineering Company. At the former the steam desilverising process, and also the sheet-rolling arrangements, described in Mr. N. C. Cookson's paper, *ante* p. 527, were seen in operation; and at the latter the working of the cradle was inspected, as described in Mr. Boyd's paper, *ante* p. 581. The Members then landed at the Coble Dene Dock Works, described below, where the steam

excavators, &c., were seen in operation; and from thence went on to the North Pier at Tynemouth, whence they returned to Newcastle by special train.

In the evening the Members and their friends were invited by the Literary and Philosophical Society, and by the Local Committee, to a Conversazione in the rooms of the Society. The adjoining rooms of the North of England Institute of Mining and Mechanical Engineers, and of the Natural History Society, were also thrown open. A large number of models, pictures, &c., illustrative of the early history of the locomotive, and of the career of George Stephenson, were exhibited, as well as a collection of microscopes. The lecture room was lighted by Swan's electric lamps, and a lecture upon this method of lighting was given by Mr. Swan himself in the course of the evening, Sir William Armstrong occupying the chair.

RIVER TYNE IMPROVEMENTS.

(Abstracted from descriptive Pamphlet by Mr. P. J. MESSENT.)

Previous to 1860 improvements in the Tyne had been limited chiefly to dredging on a small scale, and to groynes and training walls thrown out into the river, behind which land was reclaimed. A bar extending about 800 ft. from west to east, at the mouth of the river, gave at spring tides a depth of 21 ft. and 6 ft. at high and low water respectively, with 600 ft. width of channel. An inner bar with stones occurred at $\frac{5}{8}$ mile above the outer bar; and a little higher the channel was abruptly contracted to 400 ft. width at the Narrows. Shields Harbour, extending about $1\frac{1}{2}$ mile up from this point, had a narrow tortuous deep-water channel, with large shoals dry at low water. Thence up to Newcastle were a series of shoals, with only a narrow serpentine channel between them, through which vessels drawing 15 ft. could get up at high-water spring tides, while at low water the depth was only 3 to 4 ft. From Newcastle Bridge to Newburn small craft alone could get up the river, and these only at high water.

In 1853 was commenced, under the late Mr. Plews, the construction of the Northumberland Dock on the north bank, about three miles above the bar, having nearly 55 acres of water space, with 24 and

20 ft. depth over the cill, at high water of spring and neap tides respectively. The dock was made by enclosing a portion of a bight in the river, where most of the coal from the Northumberland coalfield was shipped; it was completed in 1857, without the traffic having been stopped during its construction.

In 1856 were commenced the Tyne piers, designed by the late Mr. Walker, at each side of the river mouth. On a base of rubble stone, deposited by barges, is erected a superstructure of concrete and built stonework. The length at present completed of the north pier is 2472 ft. or 0·47 mile, with submerged base extending 350 ft. further; and of the south pier 4495 ft. or 0·85 mile, with 610 ft. of submerged base beyond.

In 1861 authority was obtained for carrying out Mr. J. F. Ure's comprehensive plan for improving the whole $19\frac{1}{4}$ miles of the tidal portion of the river, namely $10\frac{1}{2}$ miles from the entrance bar up to Newcastle bridge, and $8\frac{3}{4}$ miles above the bridge to the boundary stone at Hedwin Streams, midway between Newburn and Wylam. In accordance with this plan, and from the protection afforded by the Tyne piers, the entrance bar has been removed, the former depth of 6 ft. at low water being now increased to more than 20 ft., which is continued up into the harbour at a considerable width; and the obstructive Narrows have been widened from 400 ft. to 670 ft. In Shields Harbour the dangerous shoals have been removed, and for a length of $1\frac{1}{2}$ miles vessels can moor in more than 30 ft. depth at low-water spring tides. Thence up to Newcastle there is now more than 20 ft. depth at low-water spring tides; and for $2\frac{1}{2}$ miles further about 18 ft. This is now being continued upwards to Scotswood and Blaydon, where there is already 12 ft. depth at low water. The dredging plant comprises six dredgers (three of over 50 H.P.), ten steam hopper-barges, forty-four wooden hopper-barges without steam power, and six steam tugs, &c.; the whole dredging plant and the repairing establishment have cost £300,000. The quantity dredged from the river bed since 1860 has been sixty million tons. The material dredged is carried two or three miles out to sea by hoppers, and deposited in a depth exceeding 20 fathoms at low water. Near Blaydon the dredged material is spread upon the land; and here the

river has been widened from 150 ft. to 400 ft., while a new cut, 400 ft. wide and nearly $\frac{1}{4}$ mile long, has been made through Lemington Point, saving $\frac{3}{4}$ mile distance between Newburn and Scotswood.

At Newcastle the old stone bridge, which was a great obstruction both to tide and to navigation, has been replaced by a Swing Bridge, completed in 1876, having four openings corresponding with those of the High Level bridge immediately above. The two central openings, each of 104 ft., are spanned by a double-ended swing bridge, pivoted on the intermediate or centre pier. The piers and abutments are of stone and concrete, and rest on foundations of cast-iron cylinders filled with concrete, which are sunk to the rock, 45 ft. below low water. The superstructure is of wrought-iron, and was constructed by Sir W. G. Armstrong and Co., as already described, p. 599.

The dangerous bend at Bill Point, on the north bank of the river about 3 miles below the bridge, has now been nearly removed by cutting back the cliff, rising 72 ft. above high water, to a distance of about 400 ft.

Northumberland Dock has been deepened and enlarged, with the addition of a jetty and wharf; below it and outside has been constructed a river-side wharf, 1100 ft. long. Above this are two self-acting coal-shipping staiths, each having three spouts; the loaded wagons, brought within about 540 yards by locomotives, run down inclines to the shipping spouts, and after discharging run off empty down other inclines: with the three spouts from 800 to 1000 tons of coal per hour may be loaded into a vessel at each staith. The staiths were completed in 1874.

On the north side of the river, below the Northumberland Dock and at the upper end of Shields Harbour, is the new Coble Dene Dock, commenced in 1874, and now within less than two years of completion. It is intended chiefly for import traffic, and will enclose 24 acres of water space, with 3650 ft. of deep-water quays; it will ultimately be extended to join the Northumberland Dock. The tidal entrance will be 80 ft. wide, with a lock 60 ft. wide and 350 ft. long. The depth of high water over the cill will be 30 ft. at spring tides, and 26 ft. at neaps. The excavation amounts to about five

million tons, of which a large portion is removed by dredgers and steam navvies, and carried out to sea by hoppers; the rest being used to level up the standage ground and the wharves behind the quays.

On the south side of the river, opposite the Northumberland Dock, are timber ponds, enclosing 87 acres and constructed in 1874, for accommodating the timber trade of the port.

The whole of the above works, since 1859, have been carried out for the River Tyne Commissioners, from the designs and under the superintendence first of Mr. Ure, and subsequently of Mr. P. J. Messent, M. Inst. C.E., the present engineer.

On Friday, 5th August, there were two alternative excursions, the first to Sunderland, and the second to the Langley Barony Lead Mines of Messrs. Bewick and Partners.

The first party travelled by special train to Sunderland station, and were thence conveyed in trams drawn by Brown's tramway engine (Proceedings 1880, p. 44) to Wearmouth Colliery (described below), which was inspected under the guidance of Mr. M. W. Parrington, the chief viewer. From thence they drove to the Southwick Engine Works of Mr. George Clark, covering about $3\frac{1}{2}$ acres, and entirely devoted to the manufacture of marine engines and boilers. Having inspected these, they crossed the river to the Pallion Shipbuilding Yard and Marine Engine Works of Messrs. Wm. Doxford and Sons, containing five slips, and having plant of the most modern type and construction for the building and engining of vessels of the largest class. The party then went on board a steamer provided by the River Wear Commissioners, and were taken down to the mouth of the river; passing under the railway bridge erected in 1879, with a clear span of 300 ft., and under the adjoining road bridge, originally built by Rowland Burdon in 1796, with six cast-iron arched ribs, and strengthened by Robert Stephenson in 1858 with

three wrought-iron tubular arches (Proceedings 1858, p. 261). At the docks the diamond drill was seen, as employed in boring holes for blasting under water, and some submarine shots were fired. The party then landed at the Chain Cable and Anchor Testing Works of the Commissioners, which were seen in operation; and were subsequently received by Mr. James Laing, Chairman of the Board, the Commissioners, and the principal members of their staff, and were conducted by them over the docks, inspecting the working of the coal staiths, the hydraulic machinery at the new Sea Lock, &c. They were then most handsomely entertained at dinner by the Engineers and Shipbuilders of Sunderland, in one of the Commissioners' large warehouses on the quay (specially adapted for this occasion); and returned to Newcastle in the course of the evening.

WEARMOUTH COLLIERY, MONKWEARMOUTH.

The sinking of this colliery was commenced in 1826 and continued without intermission for nine years, reaching the Maudlin or Bensham seam in 1835, at a depth of 532 yards from the surface. In passing through the magnesian limestone, feeders of water amounting to 2000 gallons per minute were met with, and pumped to the surface; until at a depth of 140 yards a suitable foundation was met with, and the water shut out by means of metal tubbing. The pits were some years afterwards sunk to the Hutton seam, which was passed through at a depth of 574 yards.

The temperature of the coal seam at this depth is found to be 90° Fahr.; but by means of a constant supply of fresh air the atmosphere in the workings is reduced to a mean temperature of 75°. The total ventilating current amounts to 200,000 cub. ft. of air per minute, which is produced by means of a furnace having a fire-grate area of 144 sq. ft., placed at the bottom of the upcast shaft, and assisted by the furnaces of six steam boilers.

The principal workings are 2 to 3 miles from the bottom of the shafts, the farthest being $3\frac{1}{4}$ miles. The haulage is done by three stationary engines, more than 20 miles of steel wire-rope being in daily use. Electric bells are employed for signalling on the engine planes.

All the coal is drawn to bank from the level of the Hutton seam by two vertical low-pressure engines, of 180 and 200 nominal H.P. respectively. The flat steel wire-ropes are $5\frac{1}{4}$ in. wide by $\frac{7}{8}$ in. thick, weighing 36 lbs. per fathom. The cages are of steel: each weighs 35 cwt., and brings up at one time eight tubs of coal, each tub weighing when full $13\frac{1}{2}$ cwt., while the cage chains weigh 5 cwt. Hence the greatest weight on the rope at the moment of lifting from the bottom is 12 tons $3\frac{1}{2}$ cwt. Each engine when fully employed can raise 90 tons of coal per hour.

SUNDERLAND DOCKS.

Sunderland is one of the largest coal-shipping and shipbuilding ports in the kingdom, and has now dock accommodation commensurate with this importance. At the mouth of the river Wear on its north bank is the Wearmouth Dock, belonging to the North Eastern Railway, and containing 6 acres of water area, with $20\frac{1}{2}$ ft. depth of high water over the cill at spring tides, and 17 ft. at neaps. On the south bank, and extending more than a mile along the seashore, are the three South Docks, belonging to the River Wear Commissioners; these all communicate, and contain together 44 acres of water area. They have recently been provided with a sea lock, designed and carried out under the superintendence of the Engineer to the Commissioners, Mr. Henry H. Wake. This lock is 480 ft. long and 90 ft. wide, with 65 ft. width at the gates. The depth over the outer cill is 27 ft. and $23\frac{1}{2}$ ft., and that over the inner cill is $25\frac{1}{2}$ ft. and 22 ft., at high water of springs and neaps respectively; and as the depth in the channel outside is about the same, much of the traffic can be worked independently of the tide. The swing bridge, the dock gates, and the sluices are all worked by hydraulic machinery. In the chain cable and anchor testing works of the River Wear Commissioners, which are of the most complete kind, the testing operations are all effected by hydraulic power from an accumulator, at a pressure of 2000 lbs. per sq. in. The quays are furnished with hydraulic and steam cranes and other appliances; and with extensive warehouse accommodation. At the docks and in the river are coal staiths, at which is shipped nearly the whole output

from numerous large collieries in the county of Durham. In the harbour, submarine rock-boring and blasting operations by means of the diamond-drill apparatus are in progress. The limits of the port extend for six miles along the coast, and up the river Wear to Biddick Ford, about eight miles from the sea.

LANGLEY BARONY LEAD MINES.

In the excursion to Langley Barony Lead Mines, the party travelled on the Newcastle and Carlisle Railway, by special train, to Haydon, Bridge Station, passing the numerous collieries and iron works at Blaydon, Newburn, Wylam, &c., and also the Fourstones colliery and lime kilns, where coal is raised from the mountain limestone formation. A lower stratum of rock at the same place yields the Prudham building stone, used for the Army and Navy Hotel, Victoria Street, Westminster, and elsewhere. At Haydon Bridge the party were received by Mr. T. J. Bewick, and were then taken in carriages to the mines. They first visited the Honeycrook adit and works, and afterwards the Leadbitter shaft and Joicey shaft, with the works adjoining. They then returned by another route to Haydon Bridge, where they were entertained at luncheon by Messrs. Bewick and Partners; and afterwards travelled back to Newcastle by special train.

The following description of the mines and works is supplied by the kindness of Mr. T. J. Bewick, M. Inst. M. E.

The Honeycrook adit, commenced in July 1871, is driven nearly due north in a "cross" vein, or one running north and south, for a distance of 82 fathoms. Here Bewick vein is intersected, and it is in this that the lead ore is met with. This vein dislocates the strata at this point, forming a fault of $5\frac{1}{2}$ fathoms throw, which increases eastwards until at Joicey shaft it is $7\frac{1}{3}$ fathoms, the north side being thrown down. Its underlay, or "hade," is slightly to the north, and the average bearing is about 67° east of north, magnetic. There is a thick covering of clay on the surface, and the existence of this vein was unknown until September 1872; since that time it has been driven upon for nearly 700 fathoms, or over three-quarters of a mile,

and worked at one point to a depth of 41 fathoms below the adit. It has so far yielded between 15,000 and 16,000 tons of lead ore.

At the Honeycrook works are dressing floors and various machines for separating the lead ore from the matrix, and from other valueless material, such as rock and clay, with which it is intermixed in the vein. The machinery comprises a steam hoist for lifting the stuff to the top of the crushing house, in which is a Blake stonebreaker and a crushing mill with one pair of rolls. Adjoining on one side are the boiler and a horizontal steam engine, and on the opposite side a complete set of jigging machinery. In a house close by are a smaller crushing mill, for further reducing the material, a stonebreaker, jigging machines, elevators, four round "buddles," and other appliances — all driven by a vertical boiler and engine. Just outside are a series of collecting pits and two more round buddles. About 50 yards lower down the valley are another set of collecting pits, and a round buddle driven by a small water-wheel. Close to the latter is a vertical boiler and a steam force-pump, for lifting the water, used in the before-mentioned works, (which now contains a little lead ore in a finely powdered state) through pipes to large settling pits situated 95 ft. higher up the hill. In these pits the mud, containing a small percentage of ore, subsides, and is afterwards removed by manual labour, or by a travelling pump, and passed over three circular buddles (Zennor's) for the purpose of separating the ore from the waste. These buddles, and the machinery in connection therewith, are driven by a water-wheel.

On the hillside, above and north of the Honeycrook works, are the Leadbitter shaft, and the dressing and other machinery in connection therewith. This shaft is 70 fathoms in depth, the adit being 26½ fathoms from the top; while below are the 11 fathoms, 27 fathoms, and 41 fathoms levels.

The first house reached, after leaving the Honeycrook works, contains a chat or small crushing mill, jigging machinery, and two round buddles, all driven by a horizontal engine by Robey and Co., supplied with steam from a vertical boiler. Just above, and nearer Leadbitter shaft, is a house containing a crushing mill, set of jigging machinery, and other appliances, with a horizontal engine for working

the same. At the shaft are three boilers for supplying steam to a double-cylinder winding engine, to one of Davey's single-cylinder non-condensing pumping engines, to a small oscillating engine working a lathe, to a Tangye engine for driving the saw-mill, and lastly to the engine before-mentioned in the crushing-mill house.

Near to Leadbitter shaft are two reservoirs, into which the water required for dressing the ores is collected. The large one is fed by a water race over three-quarters of a mile in length, and the small one by the water pumped from the mine.

About 700 yards to the north-east of Leadbitter shaft is the Joicey shaft, with dressing and other works. This shaft is nearly 41 fathoms in depth, and as yet the only communications between it and the workings are the adit and the 11 fathoms level—the former nearly 27 fathoms, and the latter 40 fathoms from the top.

The dressing floors are first reached. The machinery here is all under one roof, and consists of a boiler, a pair of horizontal engines, a Blake stonebreaker, large crushing mill, chat or small crushing mill, a complete set of jiggers, and other appliances. The necessary buddles for dressing the sludge and slime are not yet erected at this place. At the shaft top are two boilers, which at present supply steam to a pair of winding engines only, but are designed to be connected with one of Davey's compound pumping engines, and to engines driving a saw-mill and workshop, which it is proposed to erect at this place.

About half a mile to the north of Joicey shaft is a reservoir for impounding the drainage water of the district, from which it is conveyed in an open race to a small service dam. Close to the dressing works and near the shaft is another reservoir, into which, when necessary, the water will be pumped from the mine. A little south of the Joicey works is a storage reservoir, into which flows all the water used thereat; and from thence it runs by a water course to the Honeycrook dressing floors.

The system of "Dressing" the Lead Ore, or separating it from the gangue, and the rock and earth with which it occurs in the vein, is first to pass it through a stonebreaker or a pair of crushing

rollers—not unfrequently indeed through both; from which, in its reduced state, it is carried through a series of inclined revolving cylinders or "trommels," each perforated with holes of different sizes. Through these holes the ore falls into the "jiggers" or sieves, which are similarly perforated. These sieves are themselves fixed, but the water in which they are placed is moved up and down by large square pistons, worked by eccentrics. According to circumstances, there are two, three, or four of these sieves placed in succession, each a little lower than the preceding one; and thus the crushed material, by the admixture and motion of the water, is carried slowly forward, the lead ore and other heavy minerals settling on the sieve, or if small enough falling through the holes into the tub beneath; from which it is occasionally taken off by a valve in the bottom. The light rock or "waste" is carried over the end of the lowest sieve, and removed by wagon or barrow to the "dead" heap. Much of the material collected on the sieves, and in the tub below, is a mixture, in a more or less united form, of ore and valueless mineral (in this case mostly sulphate of baryta), or of ore and rock. When in this condition it is further reduced, by being again crushed in a smaller mill, in which the rolls are set nearer together. A considerable proportion is here crushed very small, and carried by the water into tanks or "classifiers"; from which it is taken to similar jiggers, perforated with smaller holes, and where the pistons have a shorter stroke and a higher speed.

Some of the ore taken from the tubs has a slight admixture of sand, and has to be passed under the "propeller" or "knife buddle." This is a cylindrical framework of iron, revolving on a horizontal axis, and carrying a series of scrapers or knife blades, fixed in spiral lines round the outside. These revolve close to a bed or channel, hollowed to the same radius; and, the ore being supplied at one end of the bed, the revolving blades not only cause it to travel forward, but also sweep it continually upwards on the curved bed against a stream of clean water flowing across it. The water separates and carries off the sand, leaving the ore almost pure by the time it arrives at the further end of the bed, from which it falls into a receptacle.

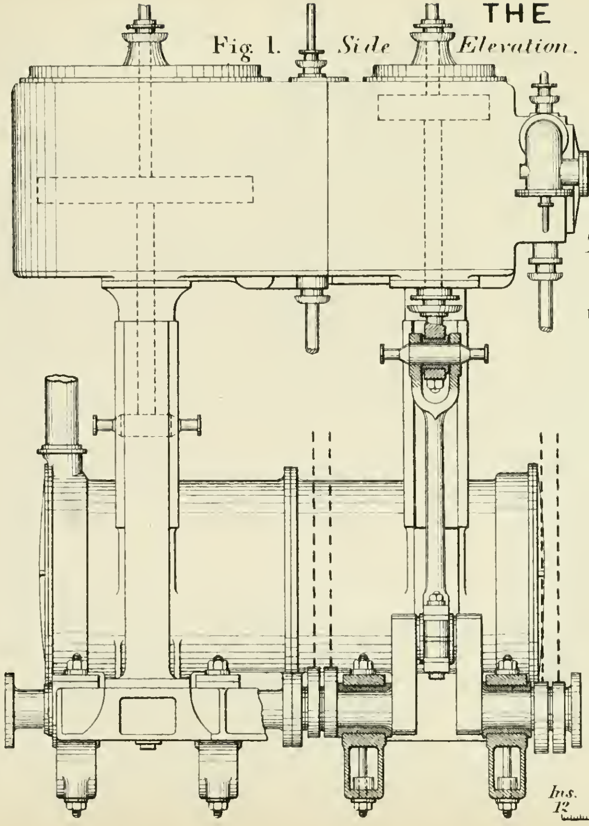
Thus the material, on being first brought out of the mine, is reduced in size and then passed through the jiggers until most of the ore is extracted. There is however still a little left, known as "slimes." These slimes are run on to the apex of a conical buddle, 16 to 20 ft. diameter, and being here mixed with an additional quantity of water (clean if practicable), flow down the slope of the cone. The ore and the heaviest of the minerals subside first, near the apex: the lighter portions go towards the periphery and settle there, or are carried away in the water. These buddles fill with deposit to the depth of a foot or thereabouts, and are then emptied by manual labour. The outer portion is thrown away, as containing no ore; the middle and upper portions are again passed over these buddles, as often as necessary, until the lead ore is nearly pure enough to send to market.

The final operation with this class of ore is to "dolly" it, that is to put the ore into an ordinary large sized cylindrical wooden tub with water, agitate it so that the whole is thoroughly intermixed, and then rapidly strike the sides of the tub with heavy pieces of wood or iron bars; in some instances this is done by hammers driven by machinery, but at these mines boys are employed in this operation. This has the effect of causing the ore to settle at the bottom or lower part of the tub, and the lighter sand or waste to come to the top. The ore is taken out of the tub by manual labour, and is now fit for market.

All the water used in the manipulation of the ore, as before described, is run into a series of pits 20 to 30 ft. long, about 3 ft. wide and 2 ft. deep; and here the bulk of the remaining mud, containing a small proportion of finely powdered lead ore, settles. When these pits become full, the mud is removed and passed, as just described, over round buddles and through the dolly tub, until practically all the ore is saved.

THE MARINE ENGINE.

Fig. 1. Side Elevation.



Compound
Two-Cylinder Engine
with Receiver,
working two cranks
at right angles.

Fig. 2.
End Elevation.

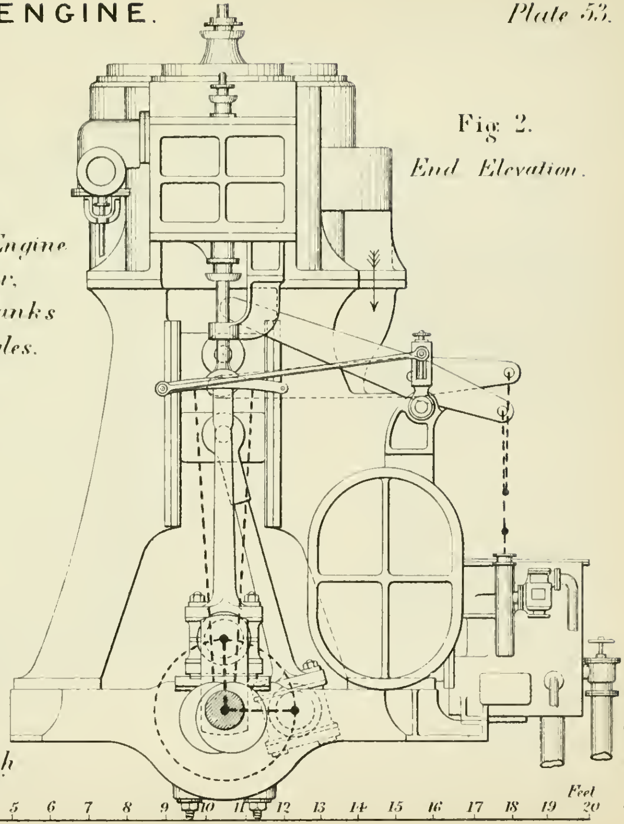
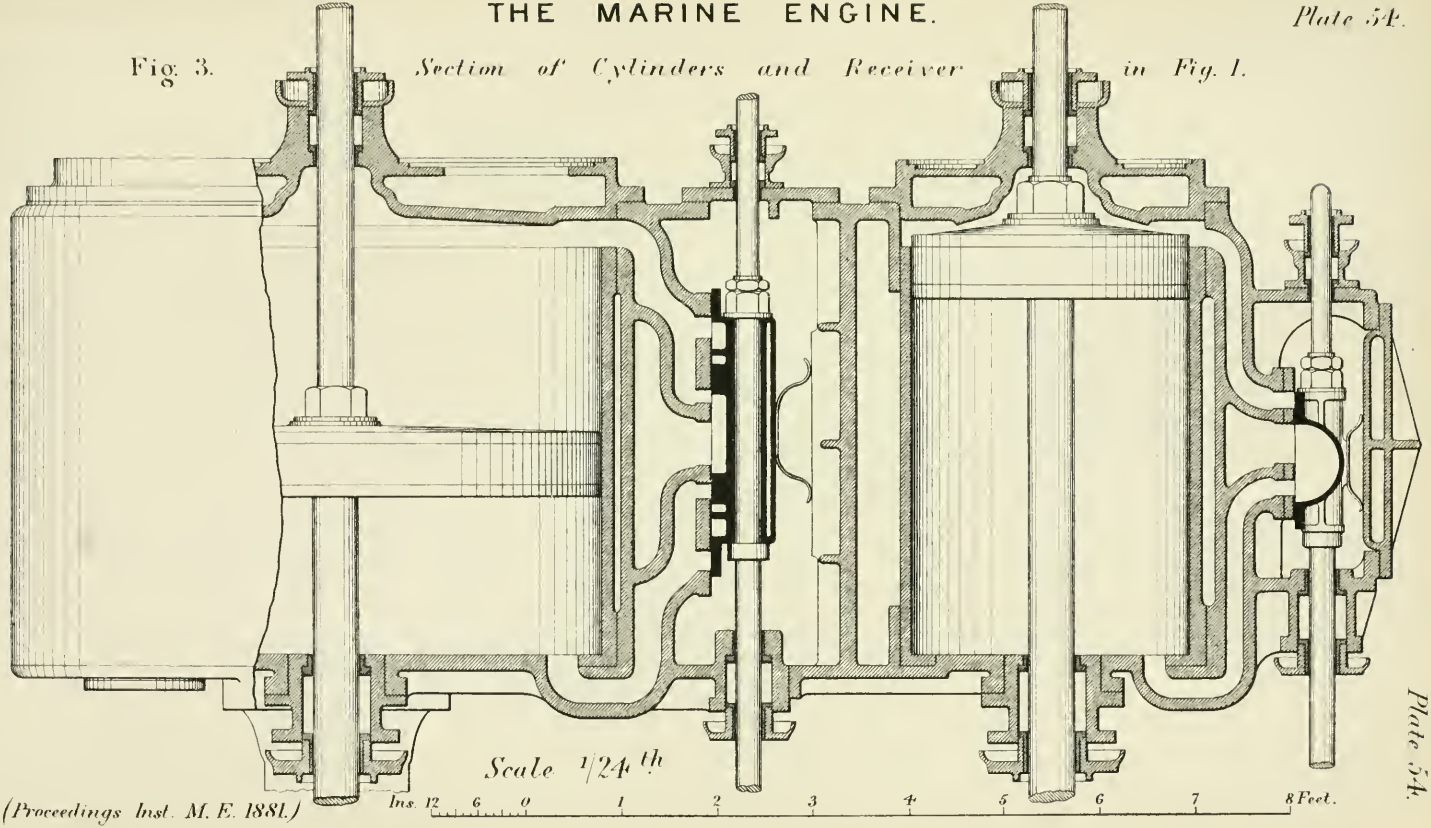


Plate 53.

THE MARINE ENGINE.

Fig. 3. *Section of Cylinders and Receiver in Fig. 1.*

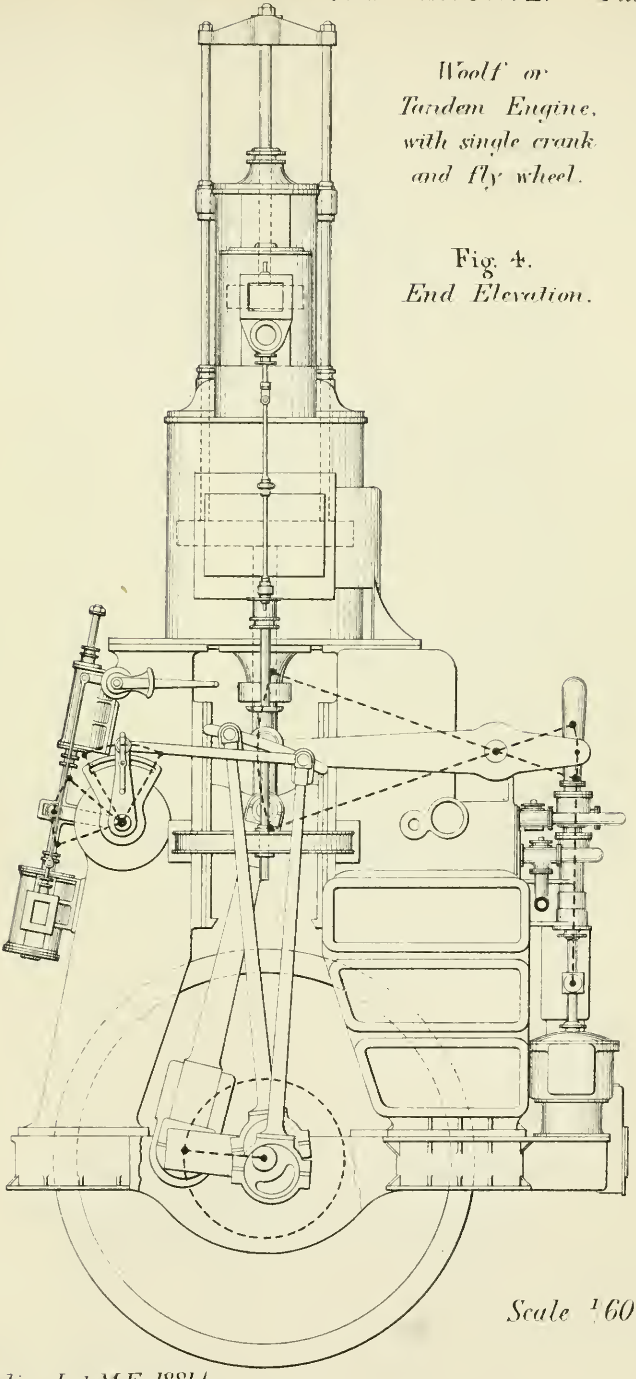


(Proceedings Inst. M. E. 1881.)

Plate 54.

Woolf or Tandem Engine, with single crank and fly wheel.

Fig. 4.
End Elevation.



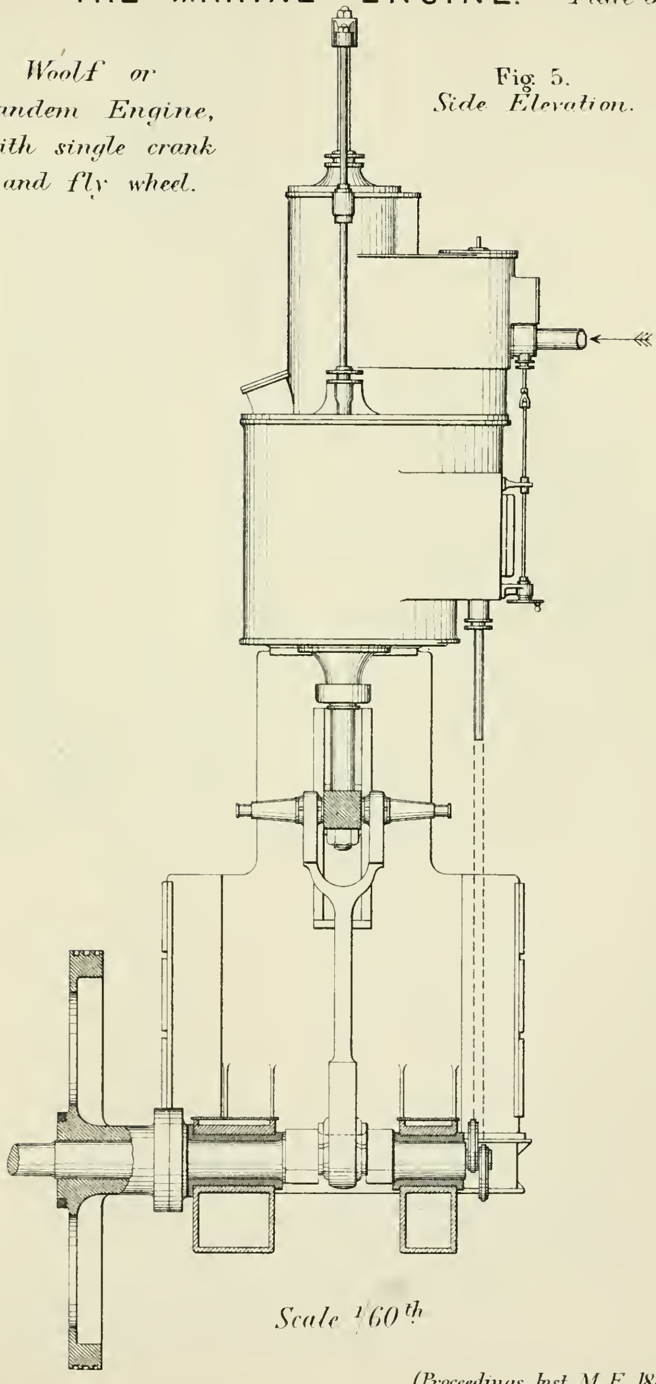
Scale 1/60th

(Proceedings Inst. M.E. 1881)

Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet.

Woolf or Tandem Engine, with single crank and fly wheel.

Fig. 5.
Side Elevation.



Scale 1/60th

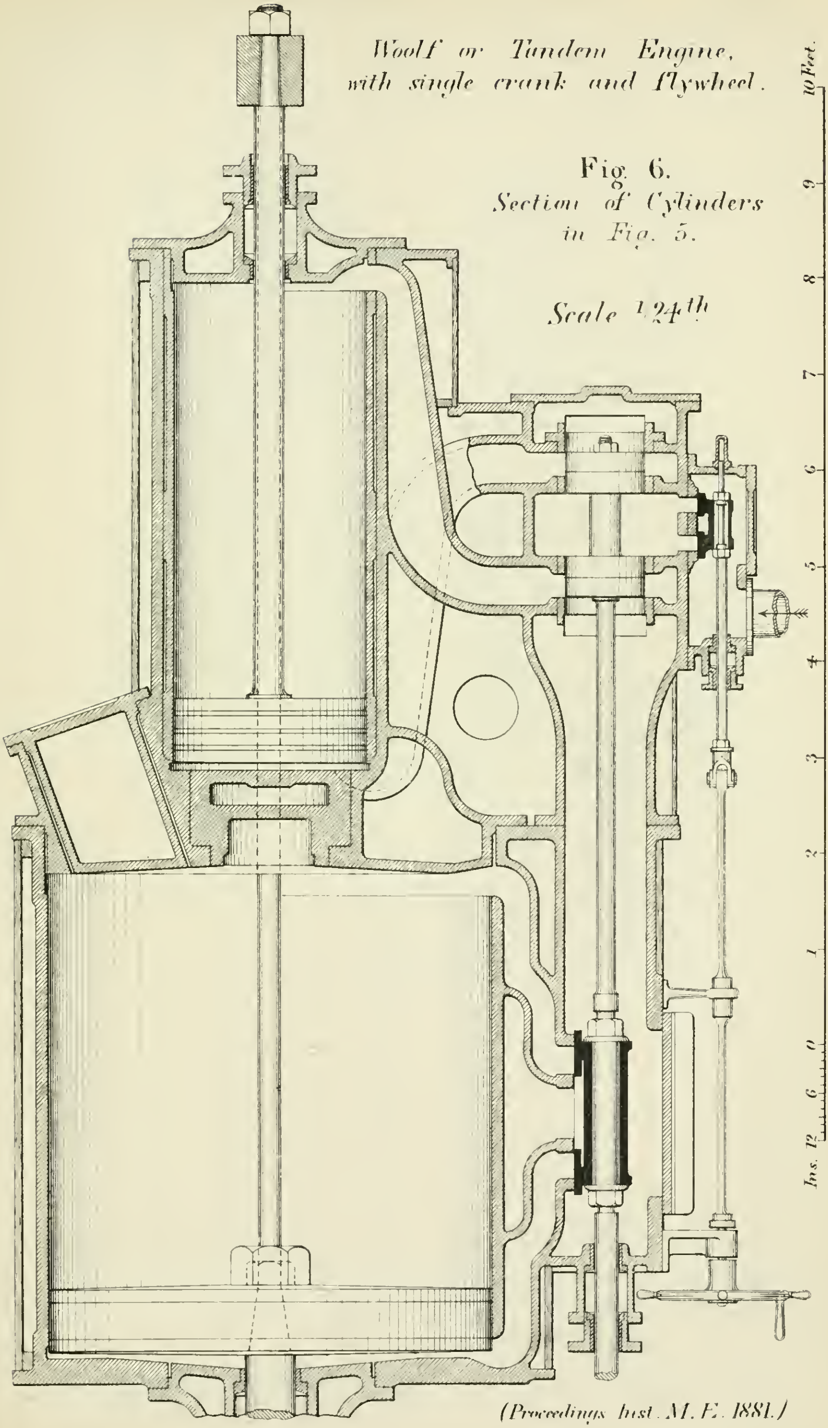
(Proceedings Inst. M. E. 1881.)

Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 *Feet.*

Woolf or Tandem Engine, with single crank and flywheel.

Fig. 6.
Section of Cylinders in Fig. 5.

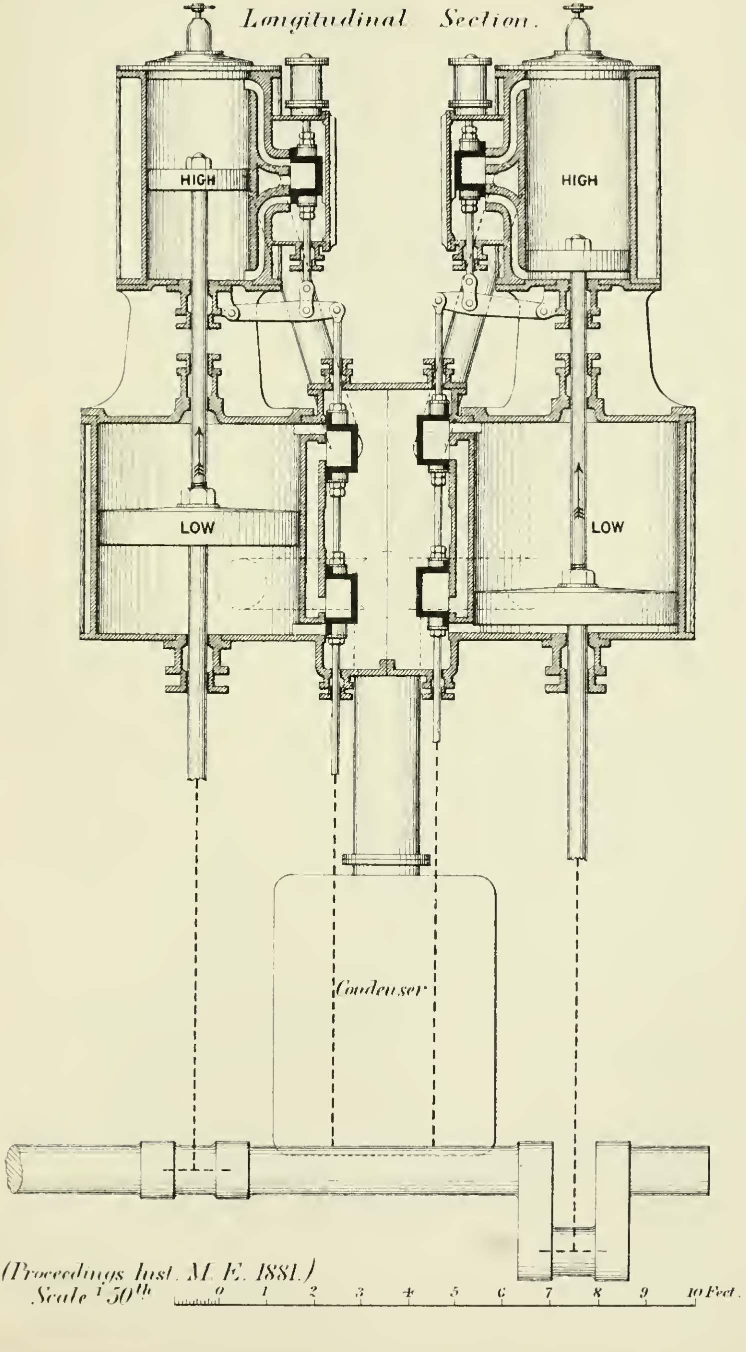
Scale 1/24th



(Proceedings Inst. M. E. 1881.)

Fig. 7. *Double Woolf or Double Tandem Engine, working two cranks at right angles.*

Longitudinal Section.



(Proceedings Inst. M. E. 1881.)

Scale 1/50th

THE MARINE ENGINE.

Plate 59.

Three-Cylinder Woolf Engines for Paddle Steamers.

Fig. 8.

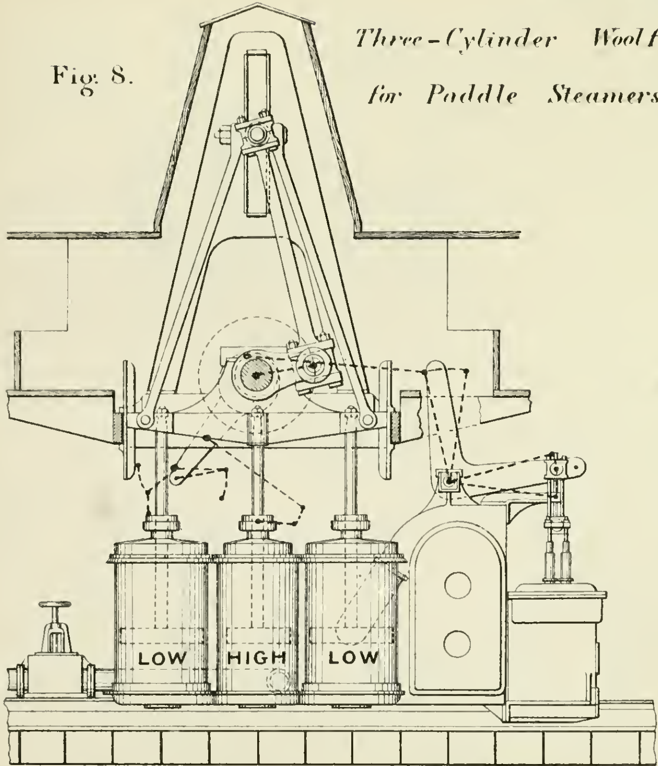


Fig. 9.

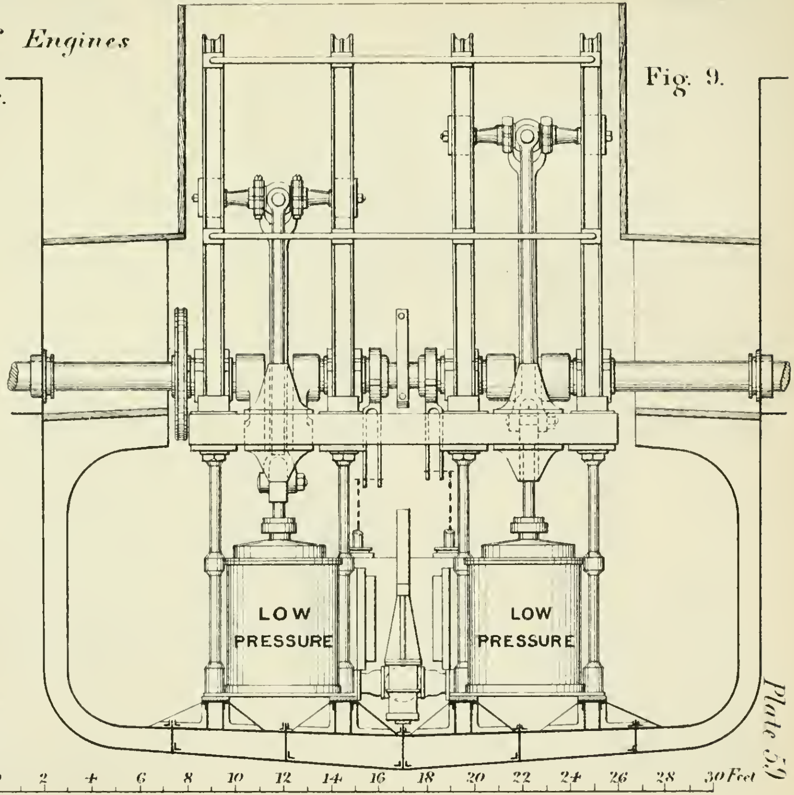


Plate 59

(Proceedings Inst. M. E. 1881.) *Scale 1/100th*

THE MARINE ENGINE.

Compound Three-Cylinder Engine, with Receiver, working 3 cranks at equal angles.

Fig. 10. End Elevation.

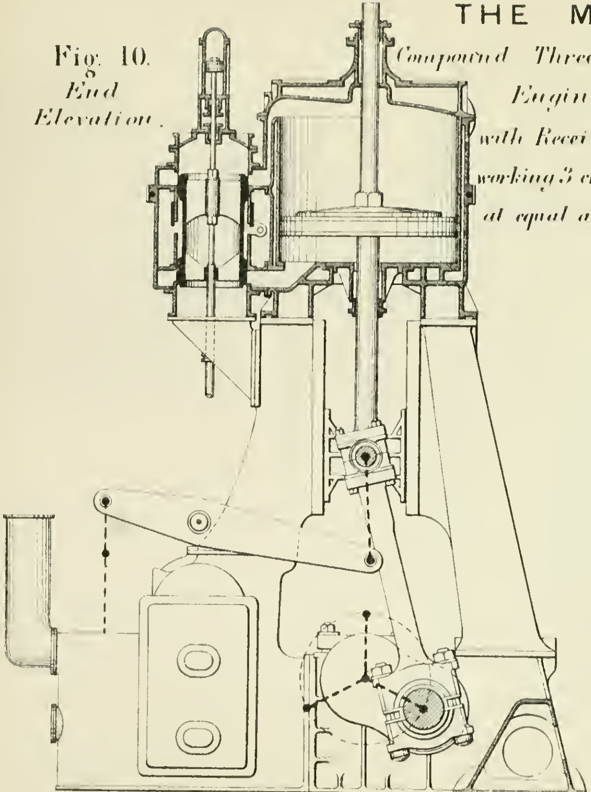
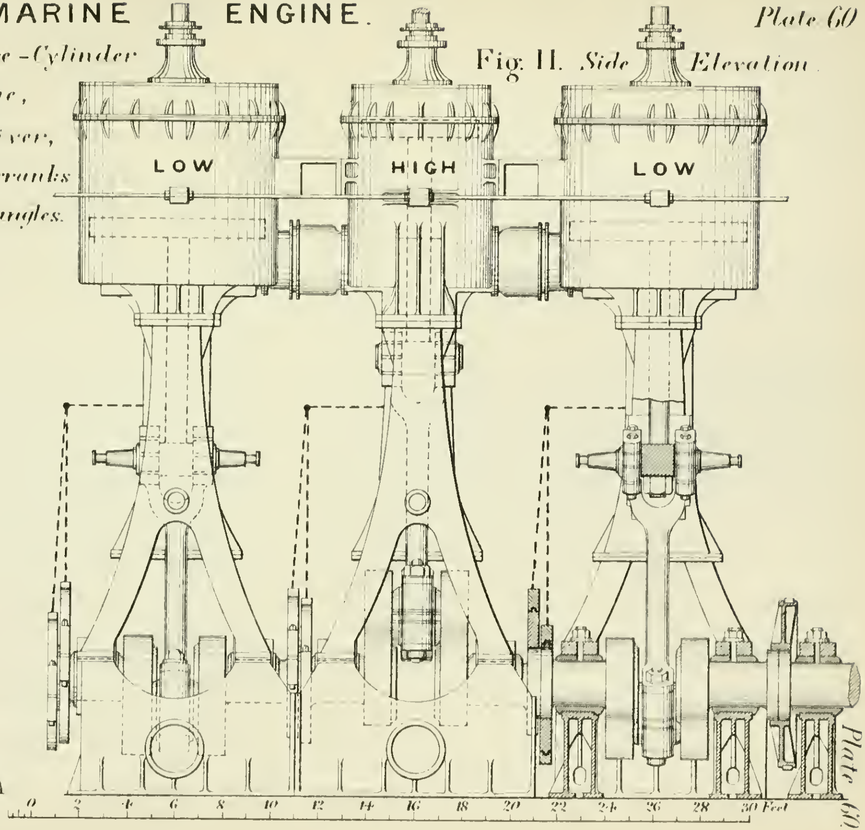


Fig. 11. Side Elevation.



Scale 1/100th

(Proceedings Inst. M. E. 1881.)

THE MARINE ENGINE.

Single-ended Marine Boiler

Fig. 12. *Back Elevation.*

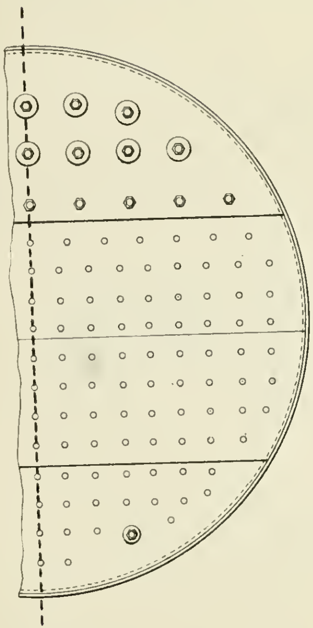


Fig. 13. *Longitudinal Section.*

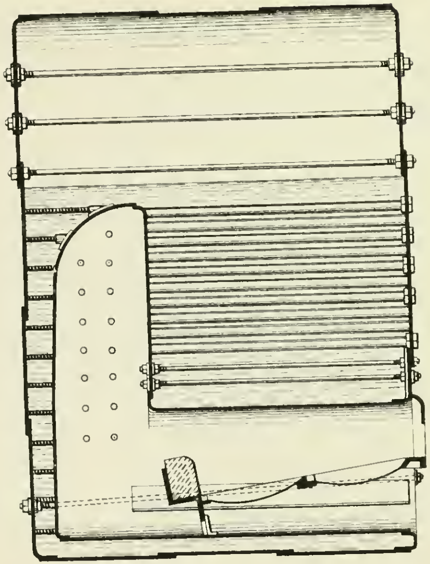
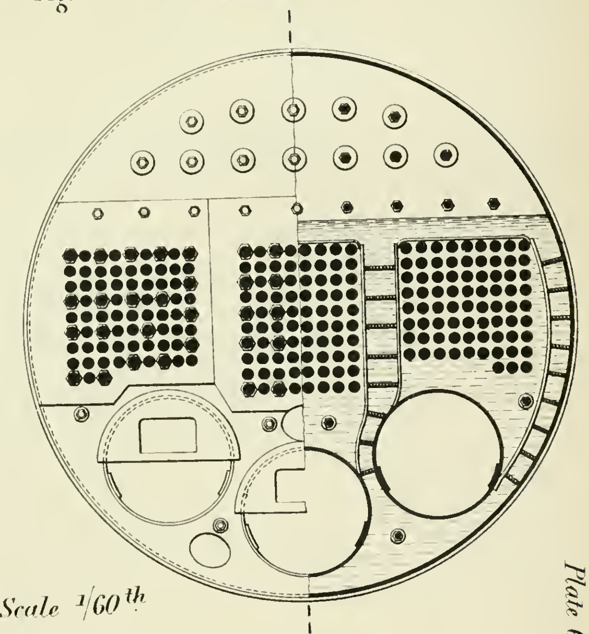


Fig. 14. *Front Elevation and Transverse Section.*



Scale 1/60th

Ins 12 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet.

(Proceedings Inst. M.E. 1881.)

Plate 61.

THE MARINE ENGINE.

Double-ended Marine Boiler.

Fig. 15.
End Elevation
and Section
at XX.

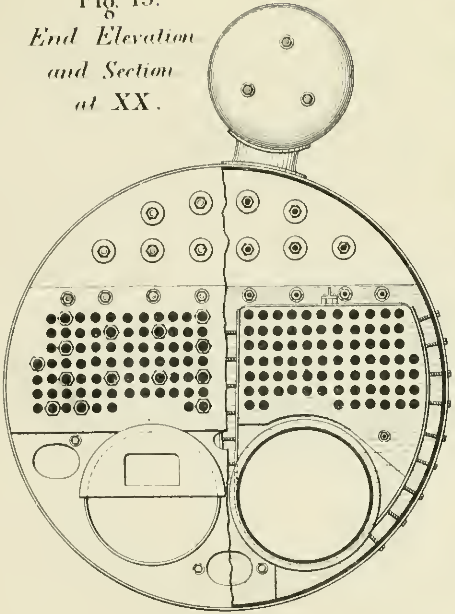


Fig. 16. Longitudinal Section.

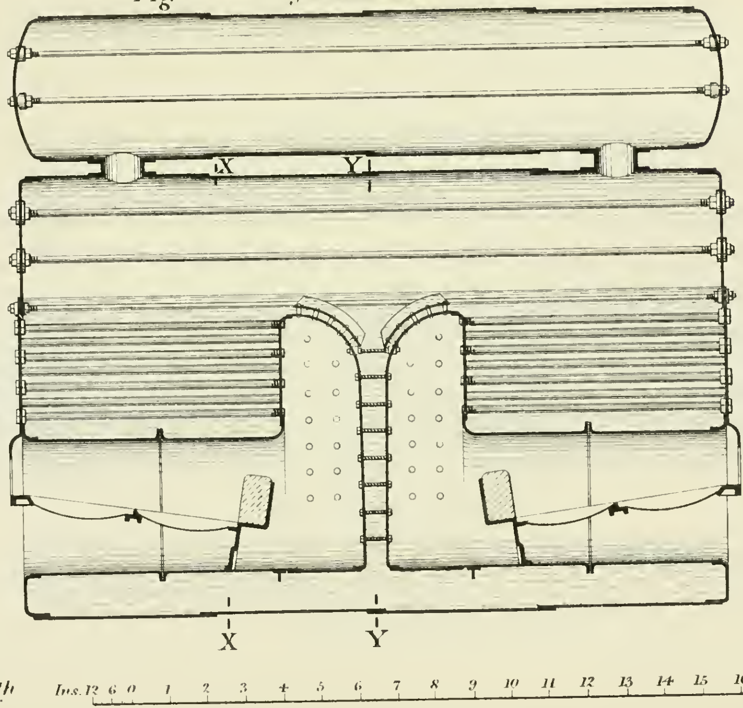


Fig. 17.
Transverse
Section
at YY.

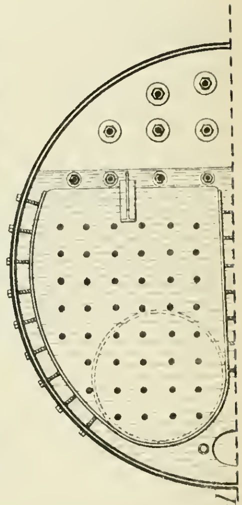


Plate 62.

(Proceedings Inst. M.E. 1881.) Scale 1/60th

THE MARINE ENGINE.

Double-ended Marine Boiler with single flame-box.

Fig. 18. *End Elevation and Section at XX.*

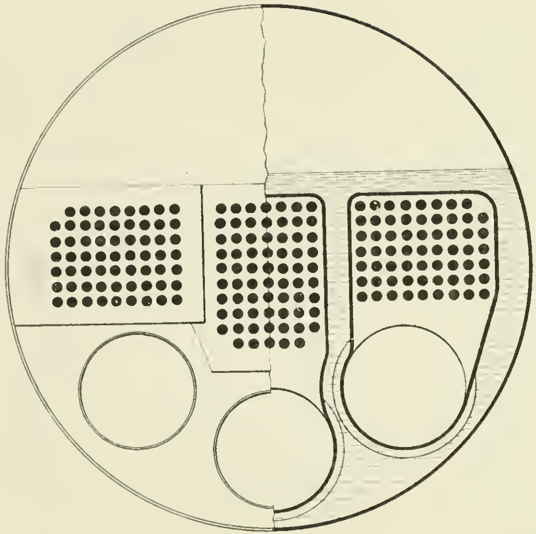
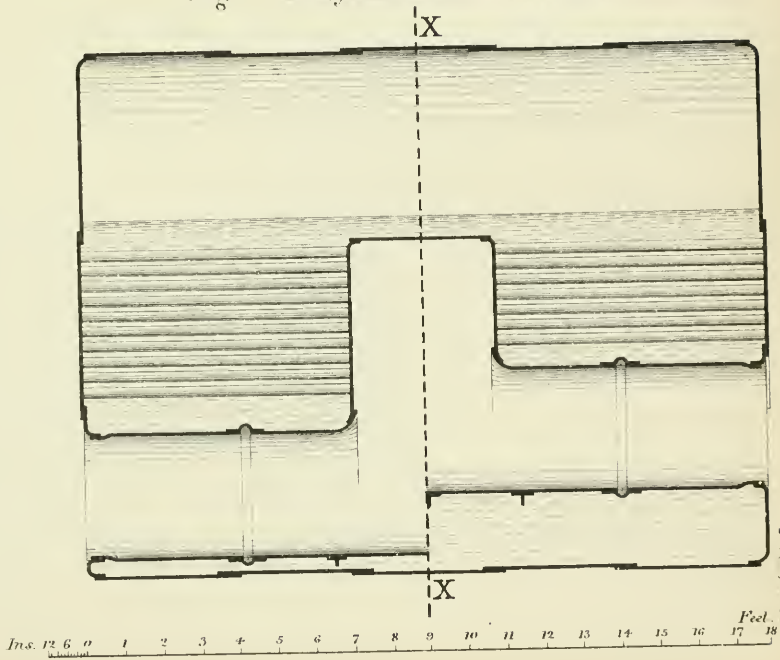


Fig. 19. *Longitudinal Section.*



Scale 1/60th

Plate 63.

Double-ended Marine Boiler.

Fig. 20. *Transverse Section.*

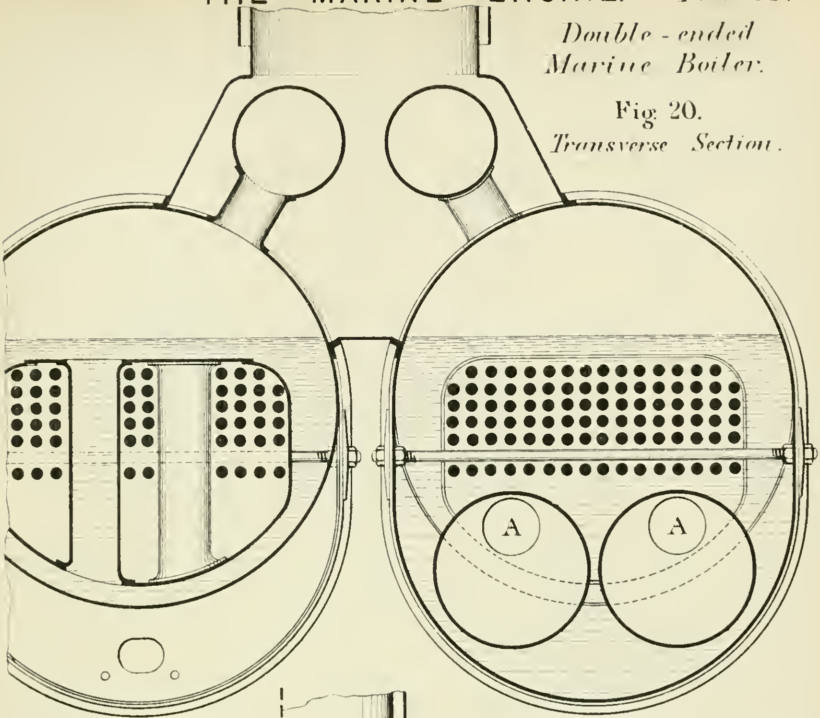
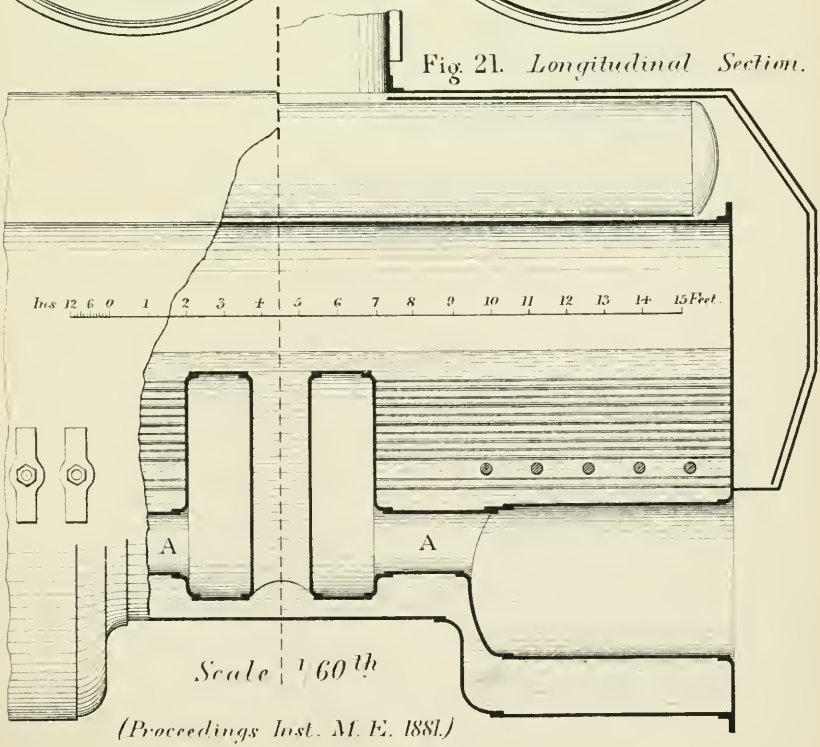


Fig. 21. *Longitudinal Section.*

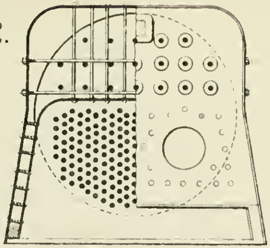


Scale 1/60th

(Proceedings Inst. M. E. 1881.)

THE MARINE ENGINE.

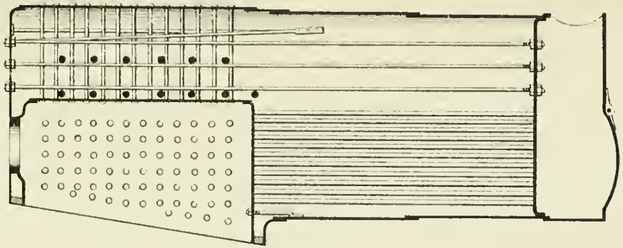
Fig. 22.



Locomotive-type Marine Boiler.

Scale 1/48th

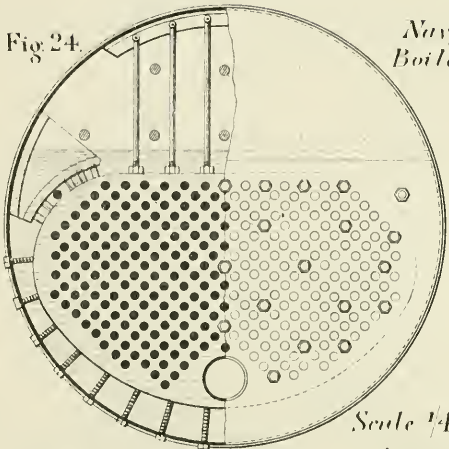
Fig. 23.



Transverse Sections.

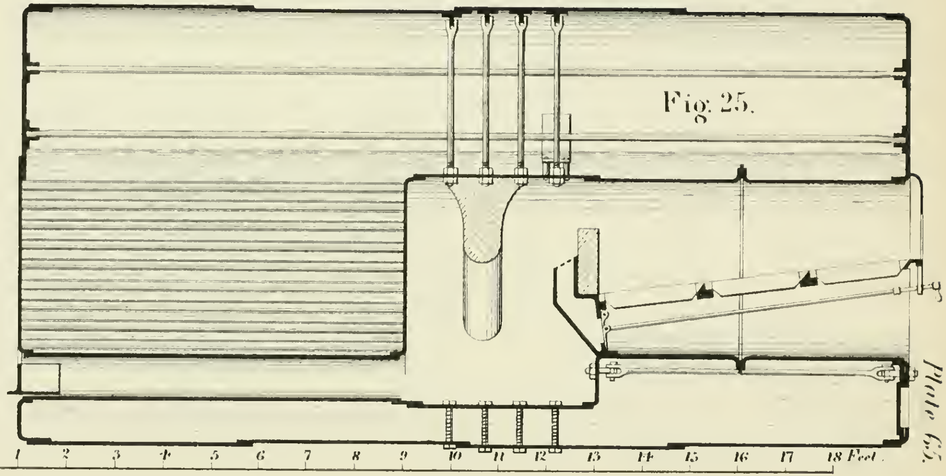
Longitudinal Sections.

Fig. 24.



Navy Boiler.

Fig. 25.



Scale 1/48th

(Proceedings Inst. M. E. 1881.)

Plate 65.

THE MARINE ENGINE.

Diagonal Framing of Engines in H.M.S. Nelson.

Fig. 26. *End Elevation.*

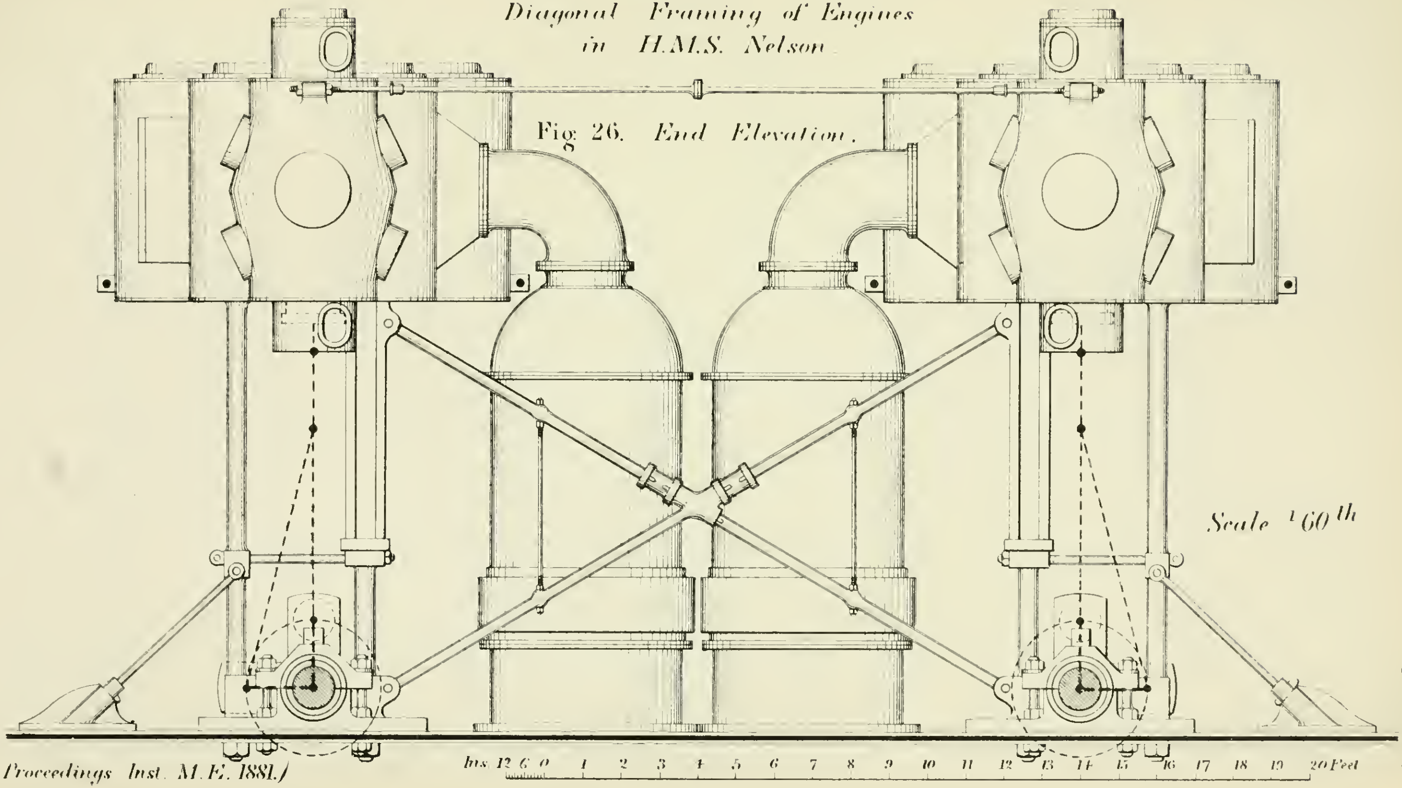
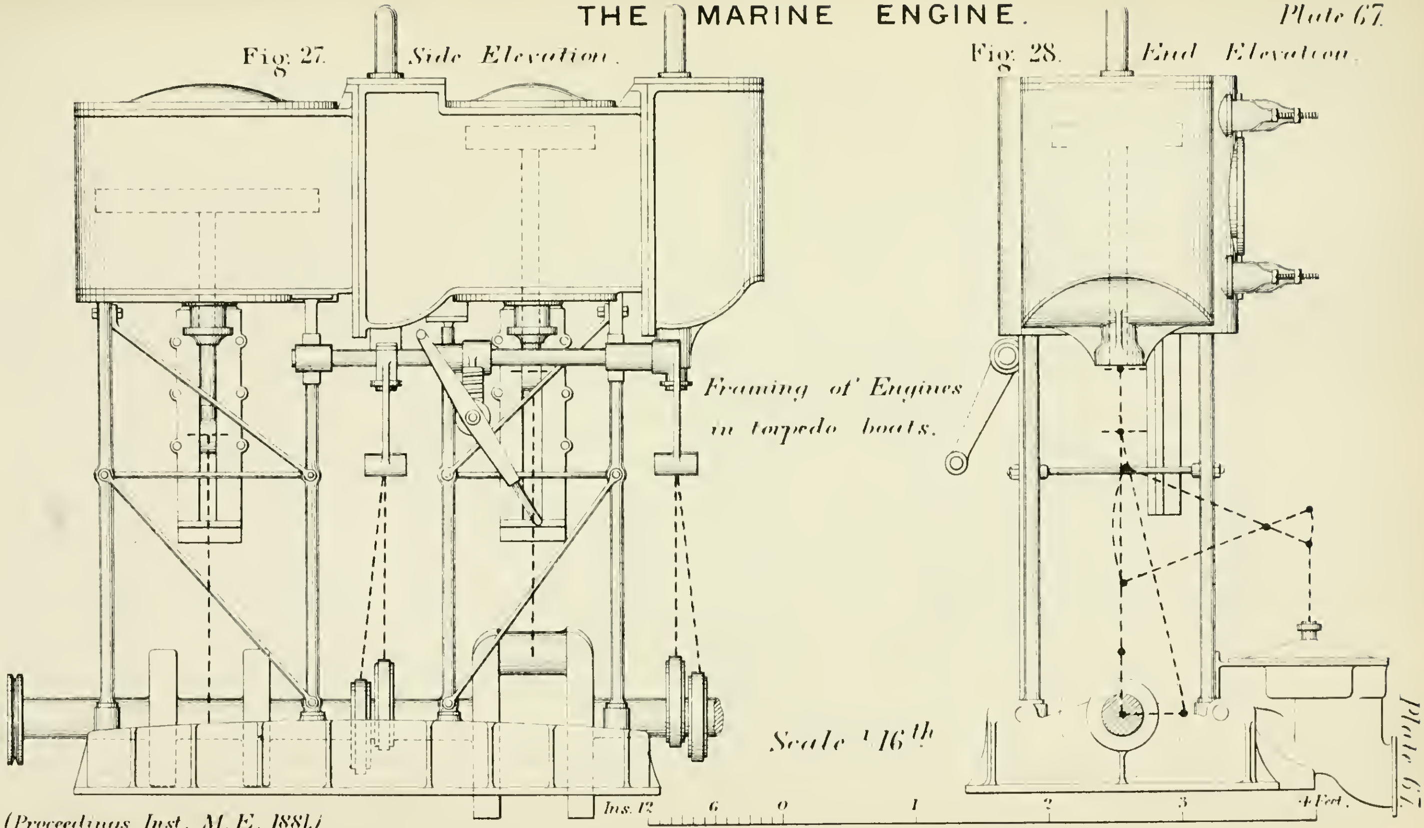


Plate 66.

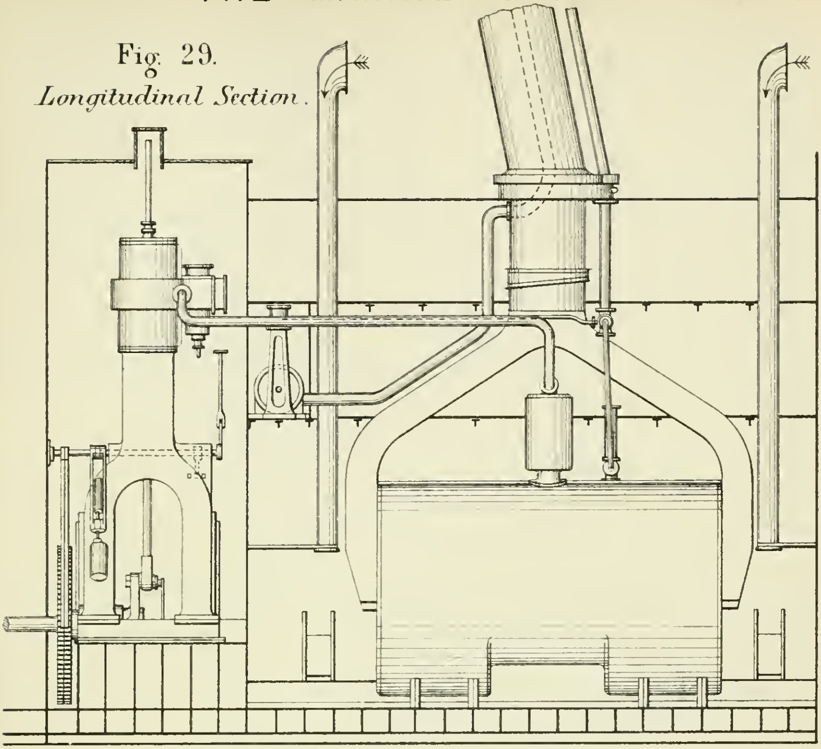
THE MARINE ENGINE.



(Proceedings Inst. M. E. 1881.)

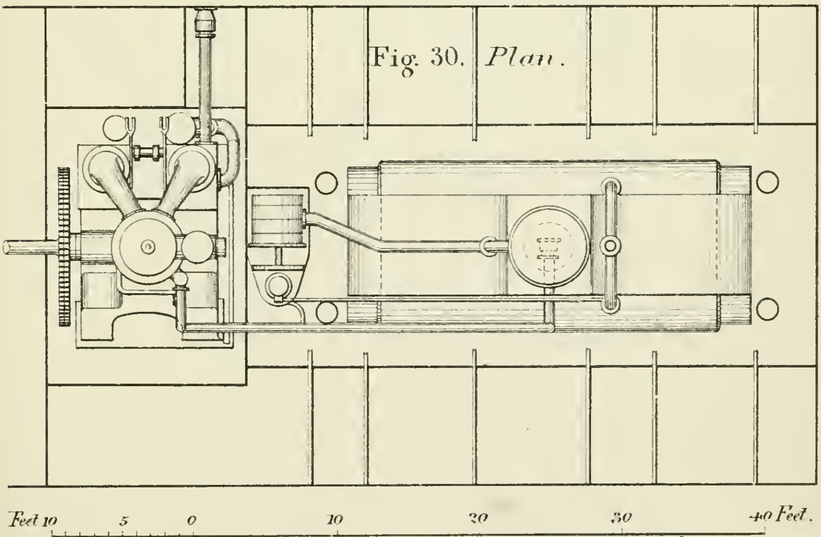
Plate 67.

Fig. 29.
Longitudinal Section.



Holt's Single Engine working overhung Crank.

Fig. 30. *Plan.*



(Proceedings Inst. M. E. 1881.) *Scale 1/160th*

THE MARINE ENGINE.

Holt's Single Engine working overhung Crank.

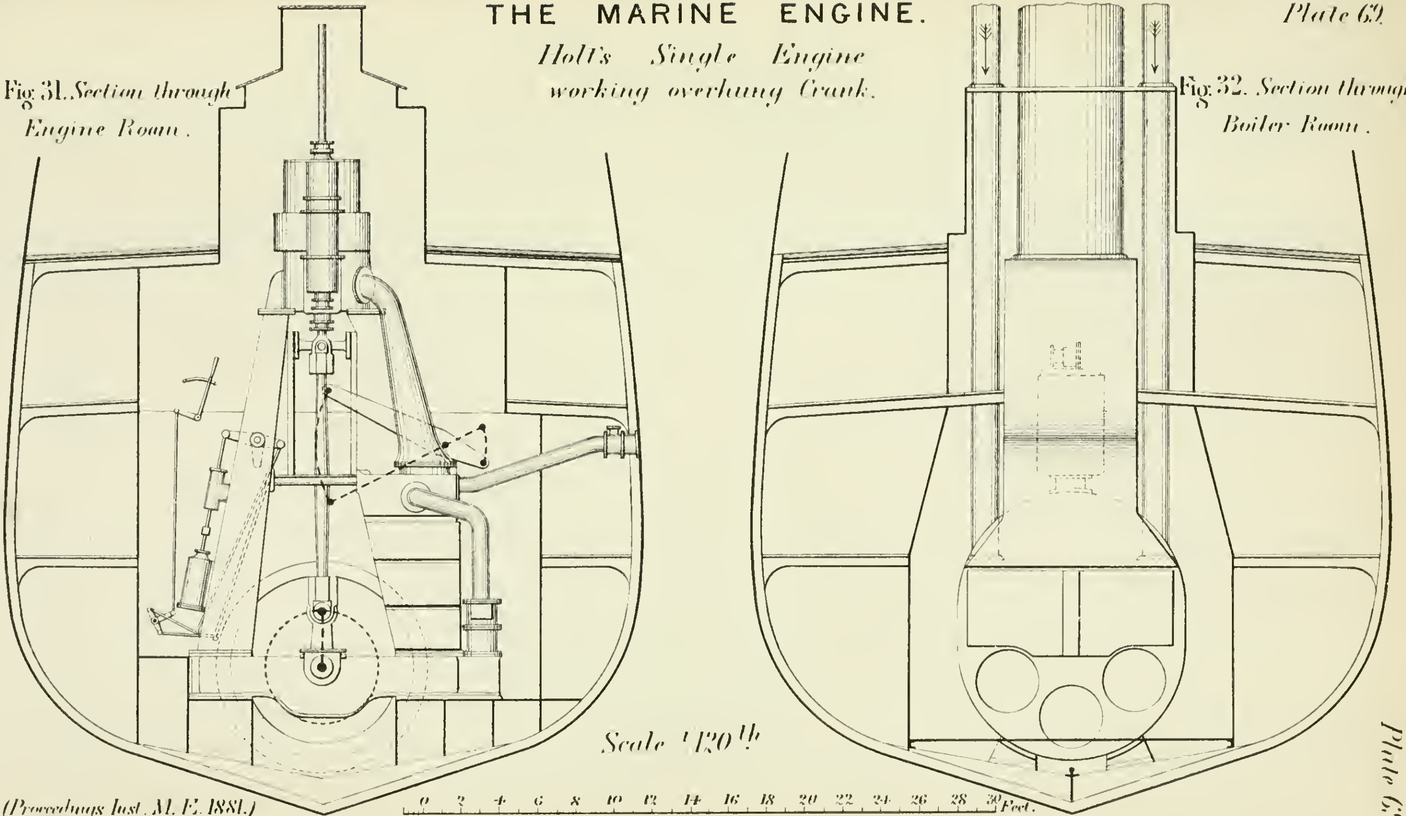


Fig. 31. *Section through Engine Room.*

Fig. 32. *Section through Boiler Room.*

Scale 1/120th

(Proceedings Inst. M. E. 1881.)

Plate 69.

THE MARINE ENGINE.

Thinning of Corners of Steel Boiler Plates in longitudinal lap-joints.

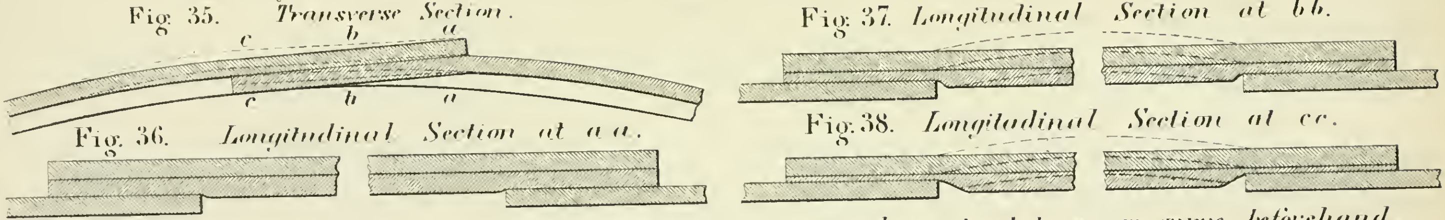


Fig. 35. *Transverse Section.*

Fig. 36. *Longitudinal Section at a a.*

Fig. 37. *Longitudinal Section at b b.*

Fig. 38. *Longitudinal Section at c c.*

Dotted lines in Figs. 35, 37, 38, indicate straining of plates at joint when not set to proper curve beforehand.

Flywheel and Overhung Crank of Holt's Single Engine.

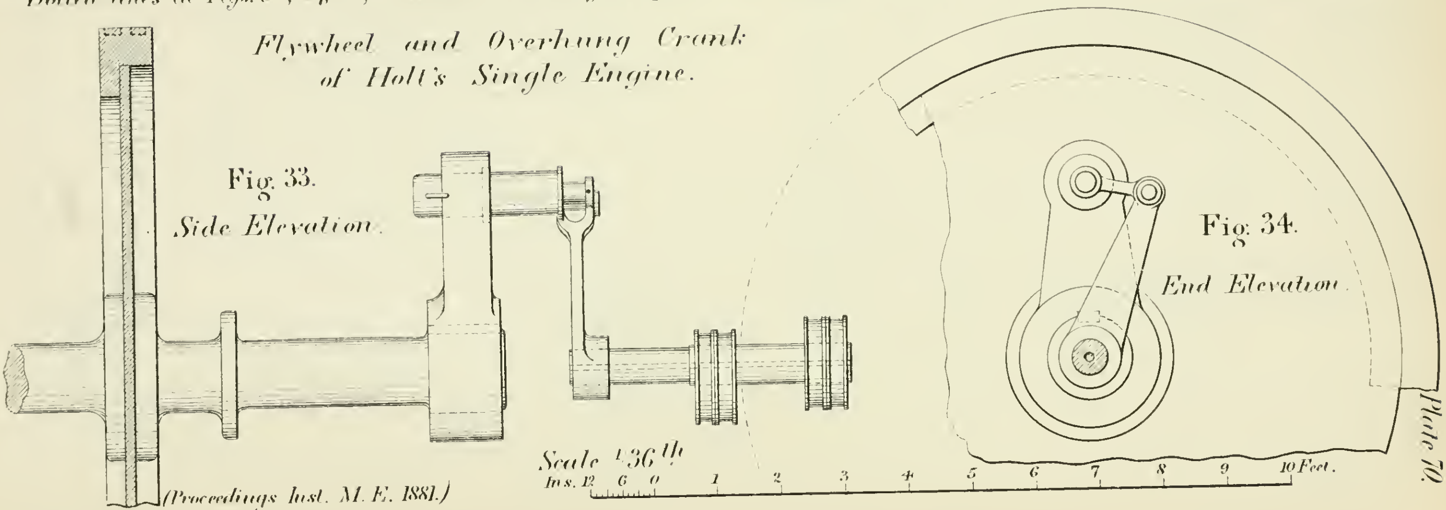


Fig. 33. *Side Elevation.*

Fig. 34. *End Elevation.*

(Proceedings Inst. M. E. 1881.)

Plate 70.

THE MARINE ENGINE.

Locomotive and Ordinary Boilers for 1500 I.H.P. Engines.

Fig. 39.
Transverse Section.

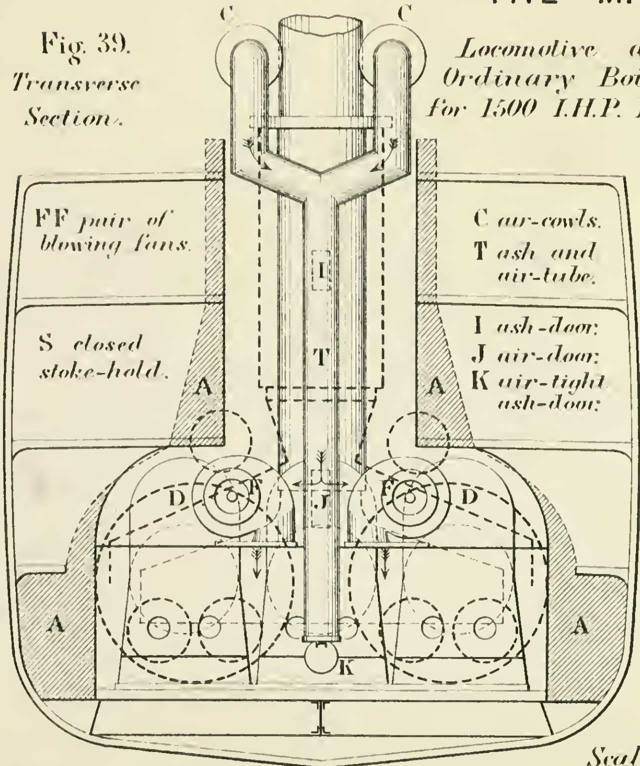
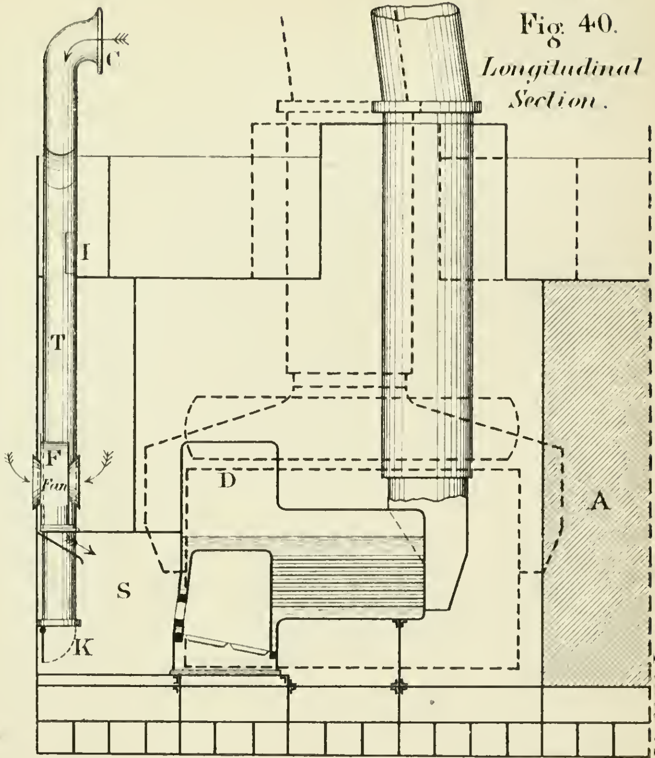


Fig. 40.
Longitudinal Section.



Scale 1/130th.
Feet 10 5 0 10 20 30 40 Feet.

(Proceedings Inst. M. E. 1881.)

Plate 71.

PRINTING MACHINERY.

Fig. 1. *Diagram of Web Printing Machine without Folder.*

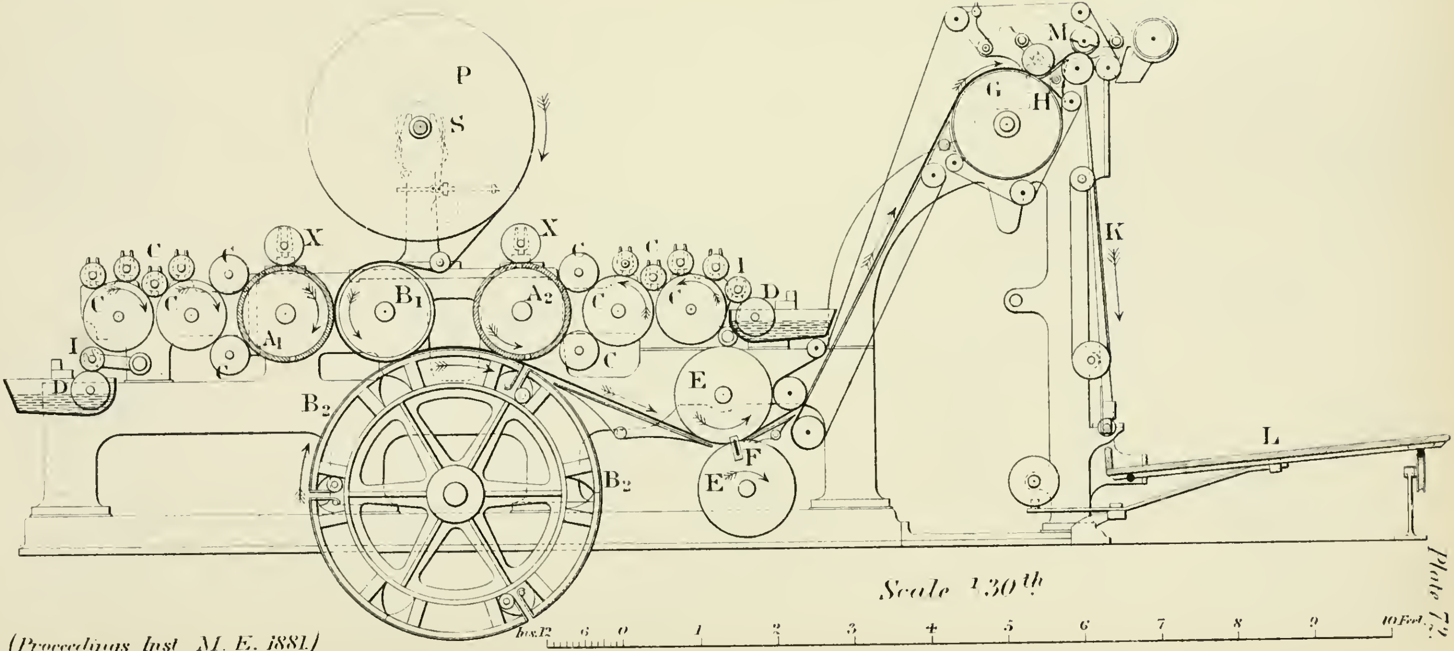


Plate 72.

Folding Machine.

Scale 1/15th

Fig. 4. Fig. 5. Fig. 6.

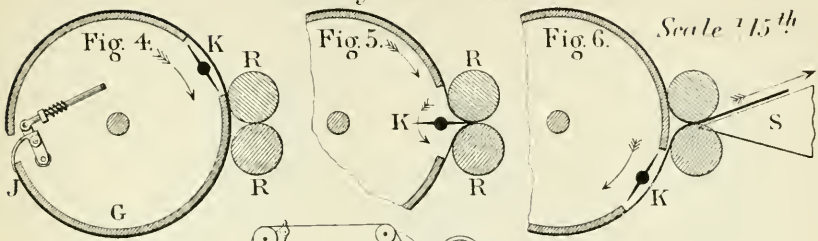


Fig. 2.
Longitudinal Section.
Scale 1/30th

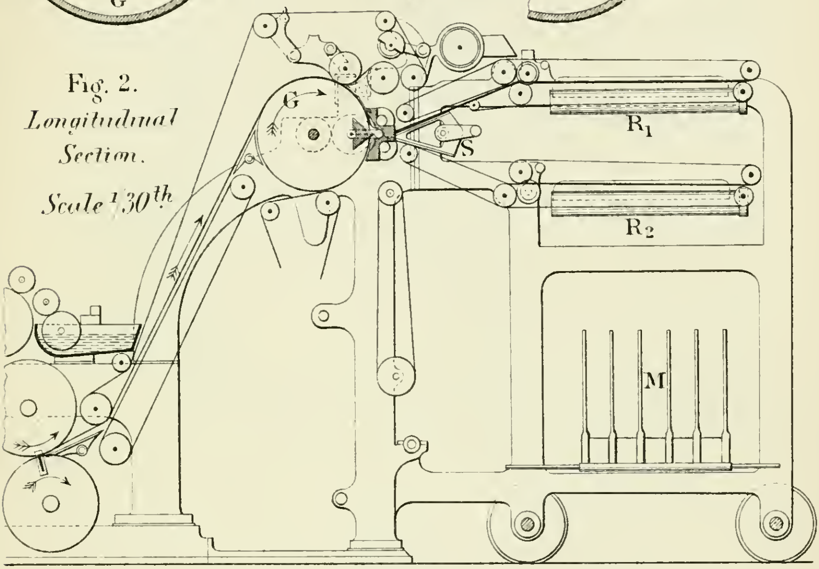
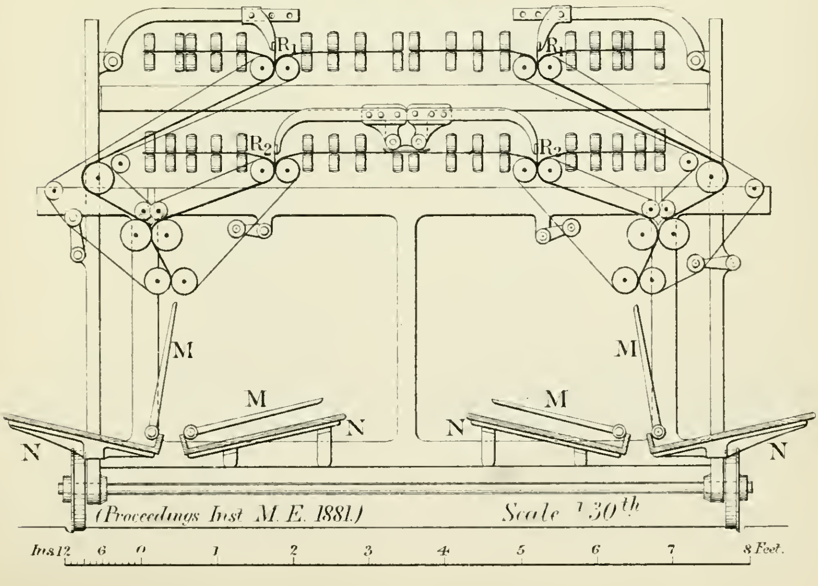


Fig. 3. *Back View.*



(Proceedings Inst M. E. 1881.) *Scale 1/30th*

Rozan Steam Desilverizing Furnace.

Fig. 1. *Longitudinal Section.*

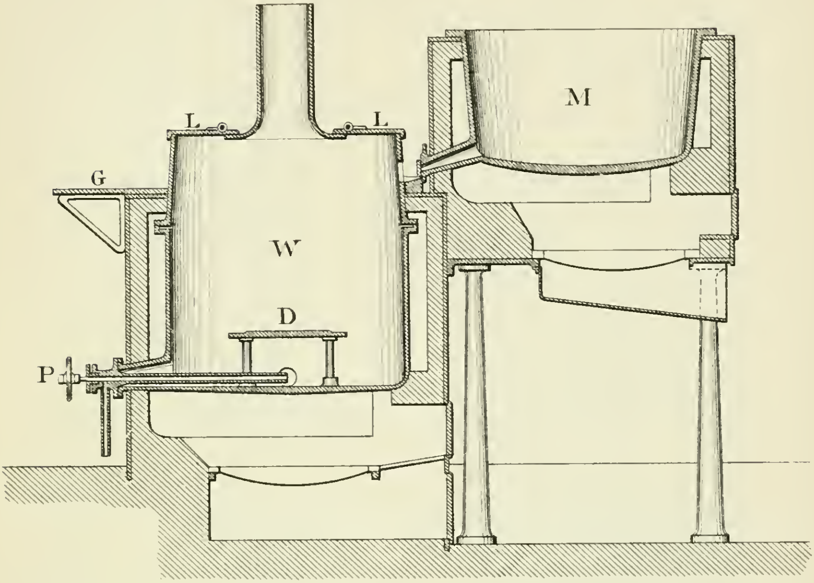
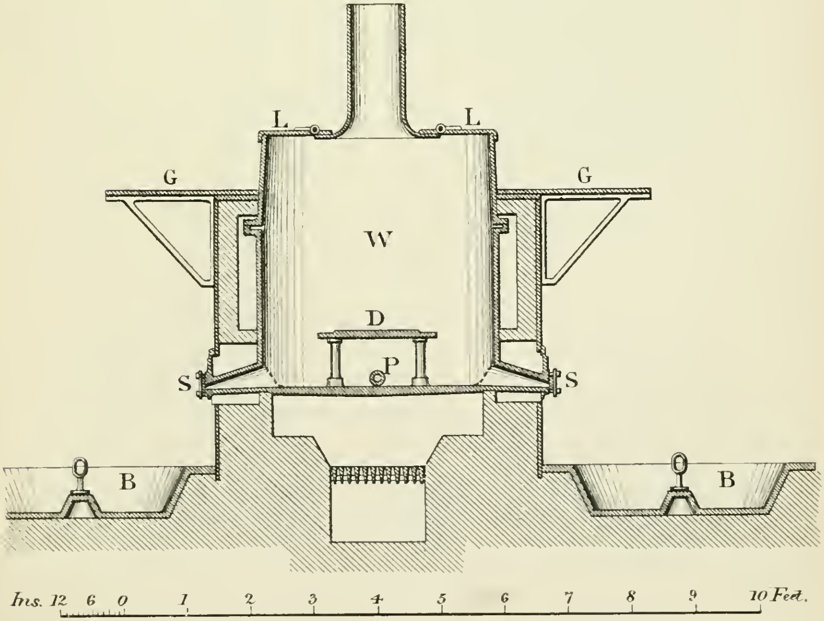


Fig. 2. *Transverse Section.*



 Scale 1/36 th

FEED-WATER HEATER AND FILTER. *Plate 75.*

Heater for Stationary Boilers.

Fig. 1.
Elevation.

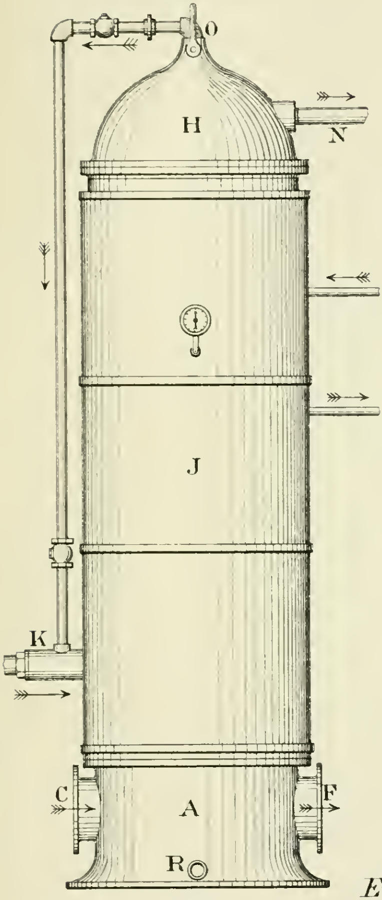


Fig. 2.
Vertical Section.

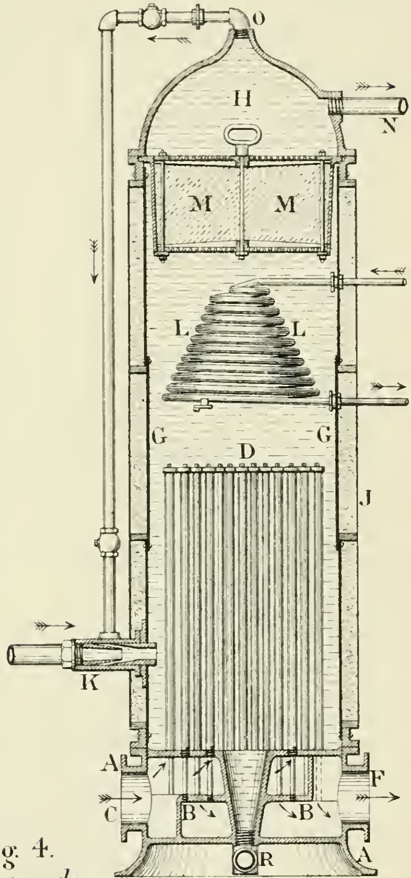


Fig. 5.

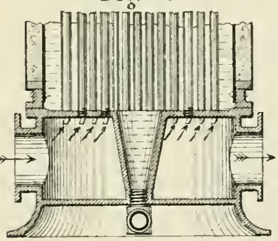


Fig. 4.
Enlarged Section of Tubes.

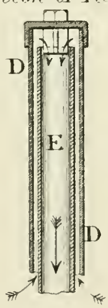
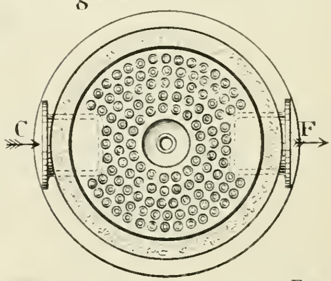


Fig. 3. *Transverse Section.*



Scale 1/48th.

Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet.

(Proceedings Inst. M.E. 1881.)

FEED-WATER HEATER AND FILTER.

Fig. 6. *Heater as applied to Side-Tank Engine, Metropolitan Railway.*

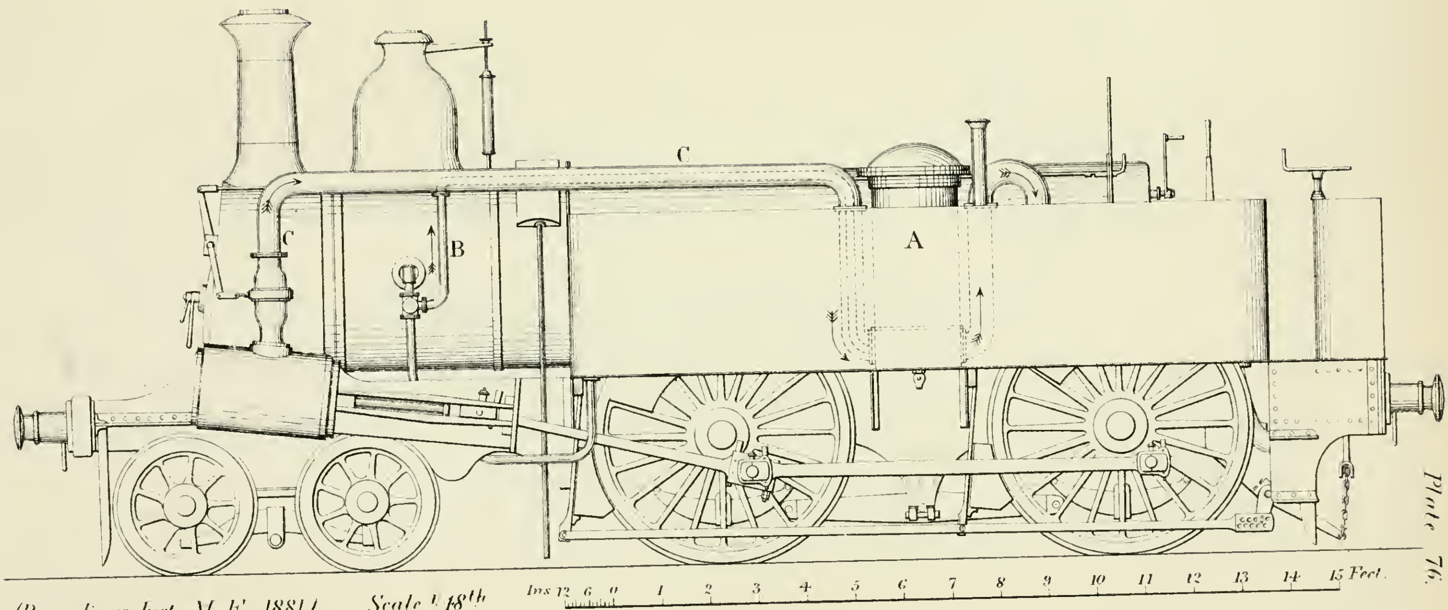
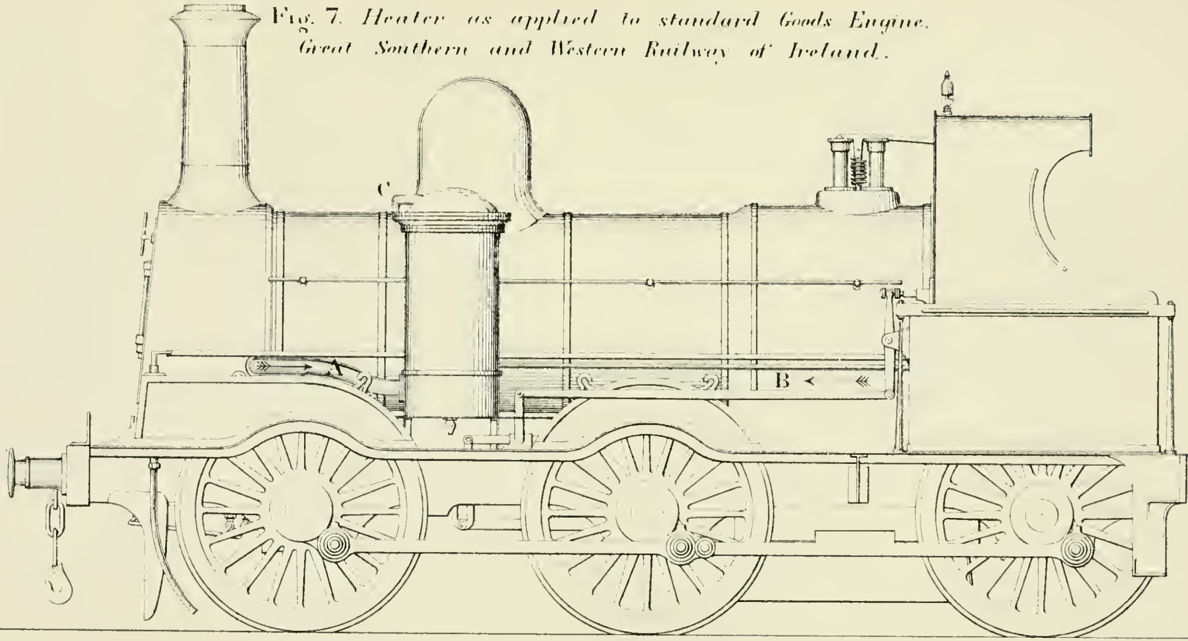


Plate 76.

(Proceedings Inst. M. E. 1881.) *Scale 1/48th*

FEED-WATER HEATER AND FILTER.

Fig. 7. *Heater as applied to standard Goods Engine. Great Southern and Western Railway of Ireland.*



(Proceedings Inst. M. E. 1881.) *Scale 1/48th* Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet.

Plate 77.

SLIPWAYS.

Plate 78.

Armstrong's System.

Fig. 1. *Elevation.*

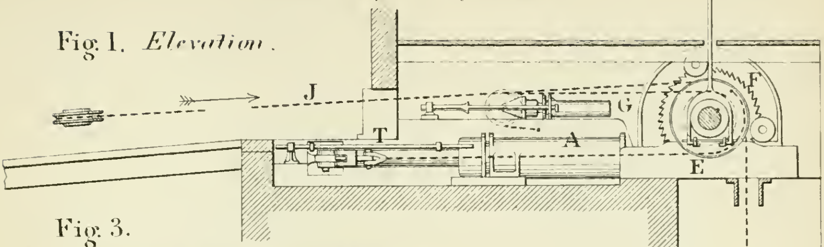


Fig. 3.
Enlarged Section of Cylinder.

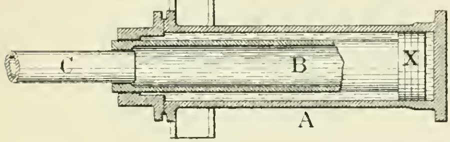
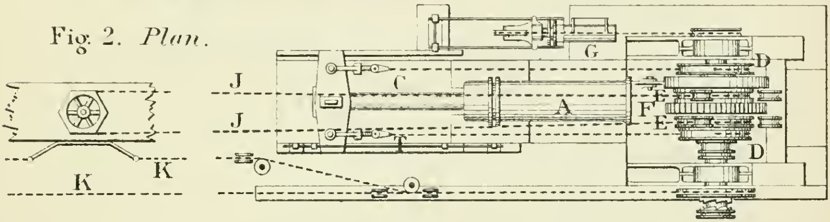


Fig. 2. *Plan.*



Day Summers & Co's System.

Fig. 4. *Elevation.*

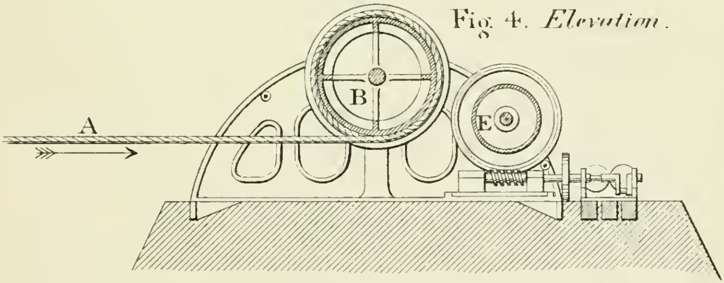
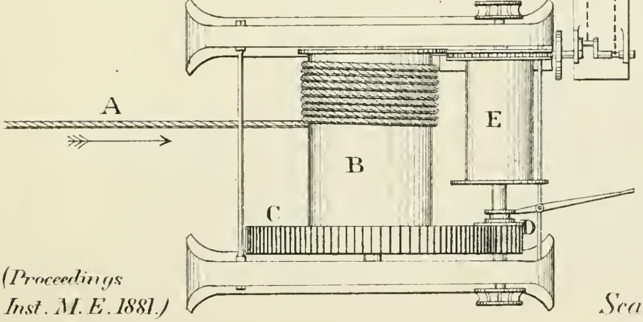


Fig. 5. *Plan.*



(*Proceedings Inst. M.E. 1881.*)

Scale 1/96th

SLIPWAYS.

Hayward Tyler and Co's System.

Fig. 6. *Elevation.*

Scale 1/96 th

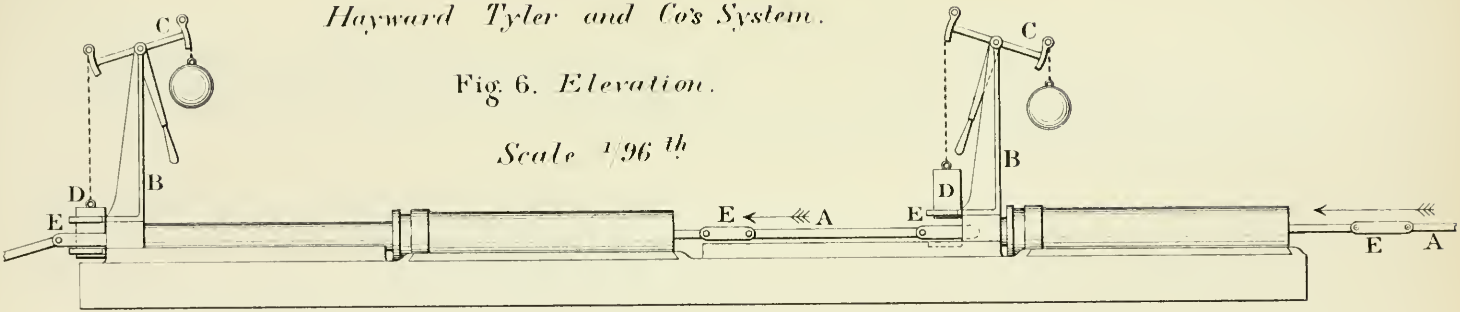
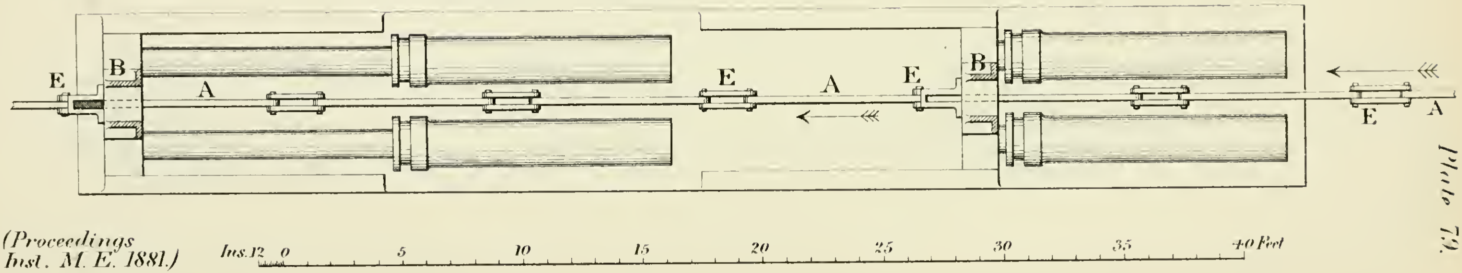


Fig. 7. *Plan.*



(Proceedings Inst. M. E. 1881.)

Plate 79.

SLIPWAYS.

Thompson's System.

Fig. 8. *Elevation.*

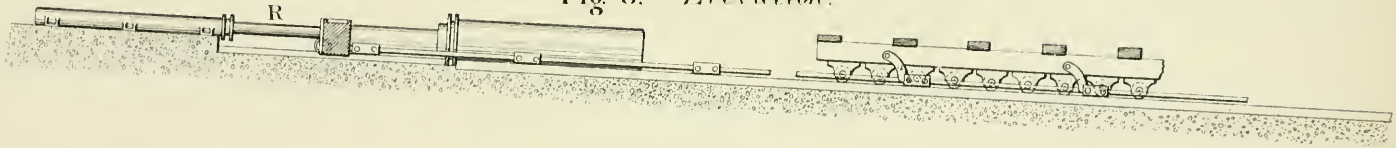
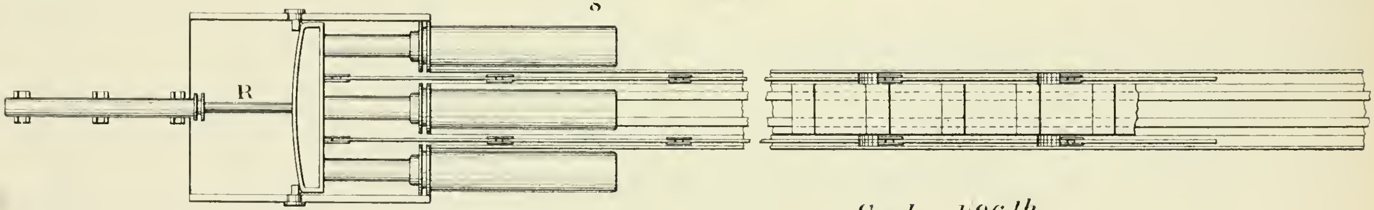


Fig. 9. *Plan.*



Scale 1/96th

Fig. 10. *Attachment of Returning Cylinder.* Fig. 11.

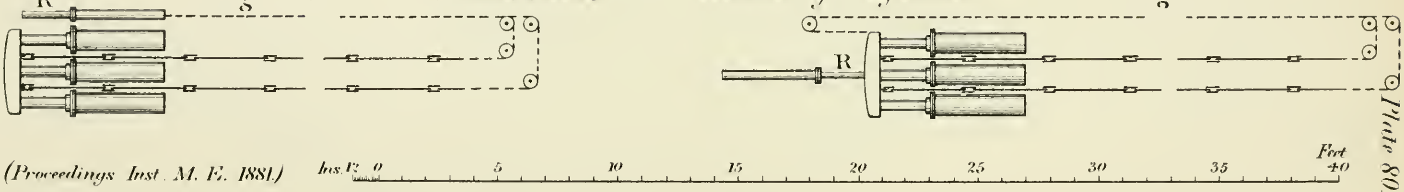


Plate 80.

SLIPWAYS.

Wallsend Slipways, General arrangement.

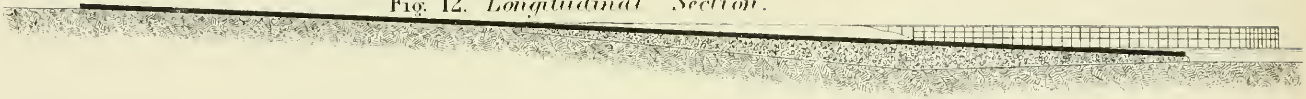


Fig. 12. *Longitudinal Section.*

Scale 1/2000th

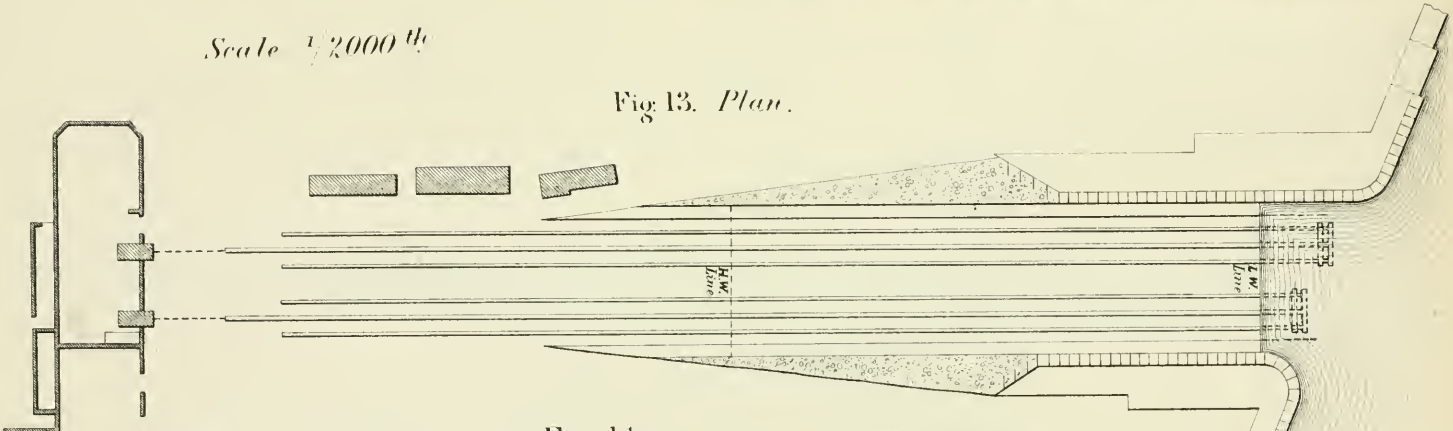


Fig. 13. *Plan.*

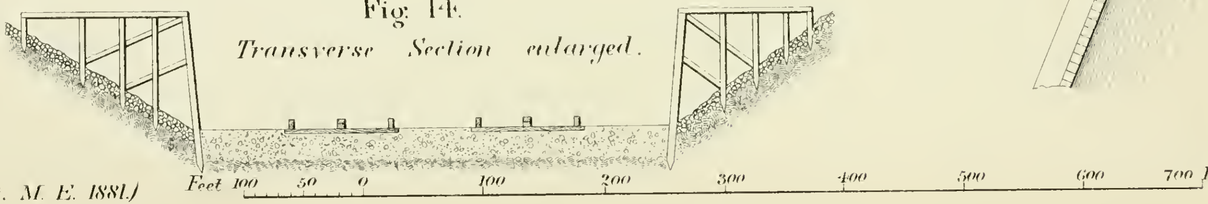


Fig. 14. *Transverse Section enlarged.*

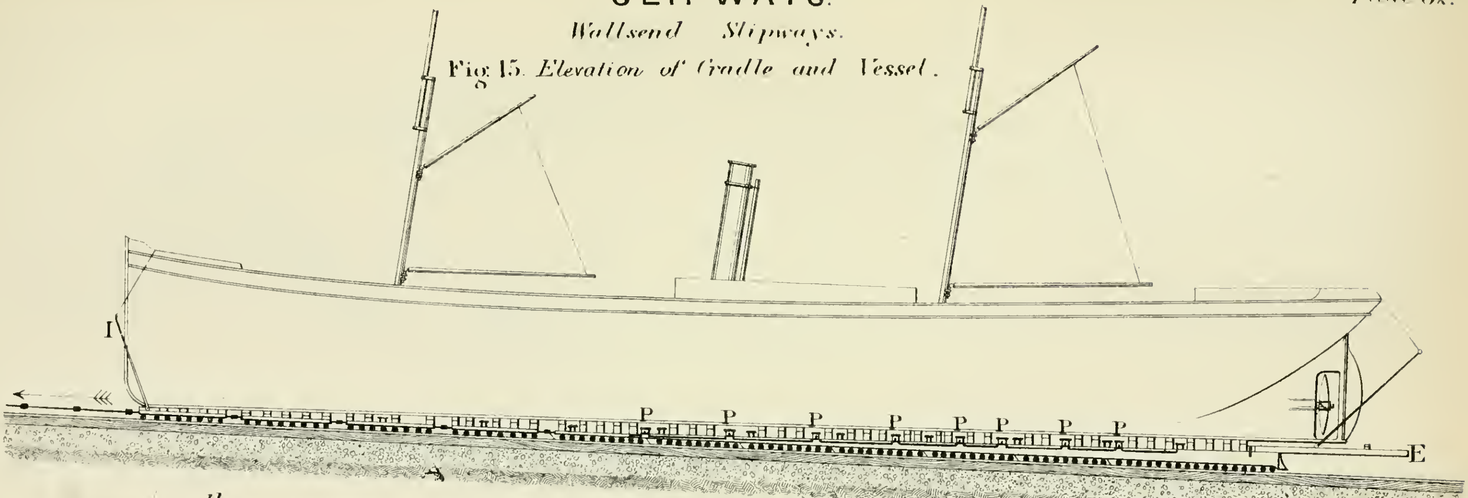
(Proceedings Inst. M. E. 1881.)

Plate 81.

SLIPWAYS.

Wallsend Slipways.

Fig. 15. *Elevation of Cradle and Vessel.*



Scale 1/500th

Fig. 16. *Plan of Cradle.*

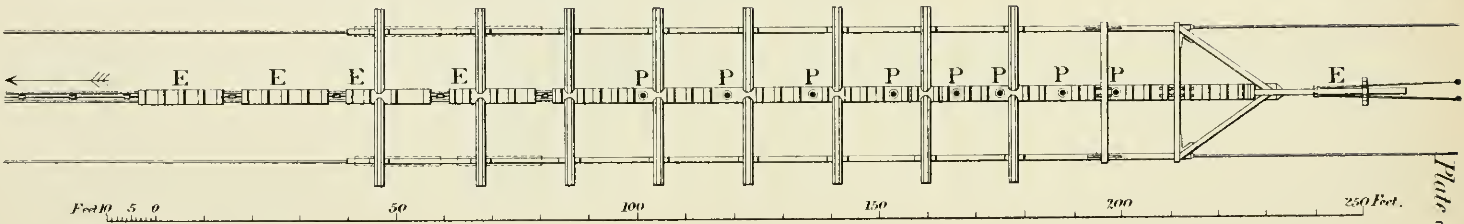


Plate 82.

SLIPWAYS.

Wallsend Slipways.

Fig. 17. Hauling Apparatus. Elevation.

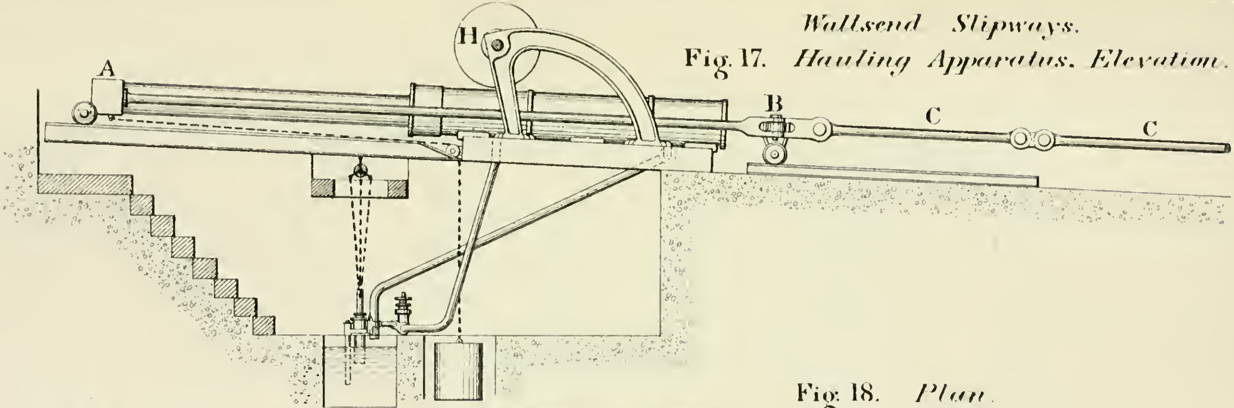
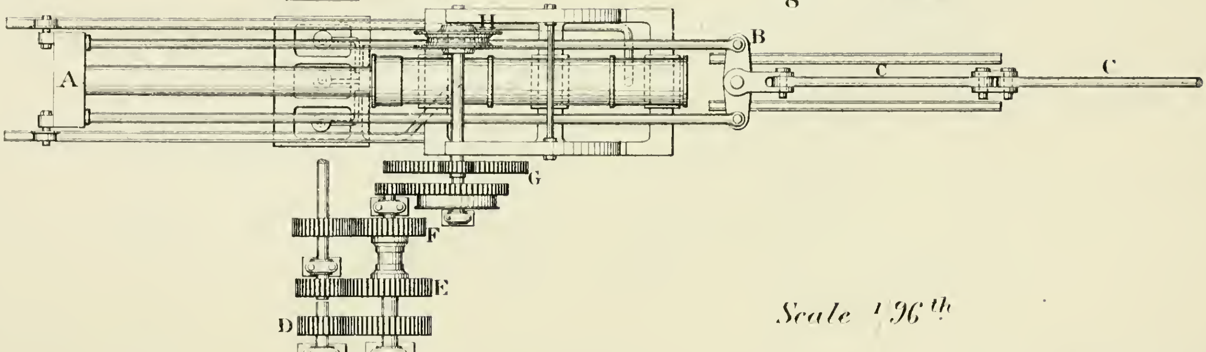


Fig. 18. Plan.



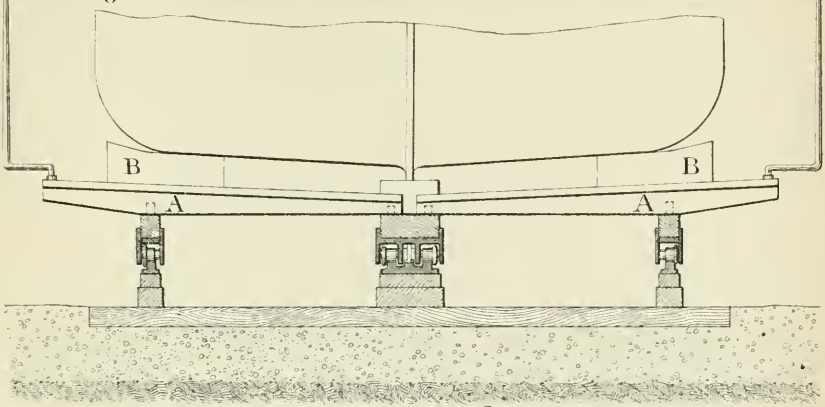
Scale 1/96th

0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 Feet.

Plate 83.

Wallsend Slipways.

Fig. 19. *Transverse Section of Cradle and Rails.*



Scale 1/120th.

0 5 10 15 20 25 30 Feet.

Fig. 20. *Enlargement of Rack and Rails.*

Fig. 21. *Double Rods. Elevation.*

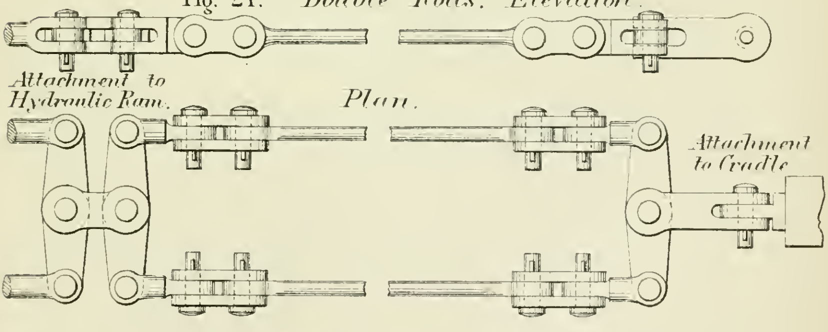
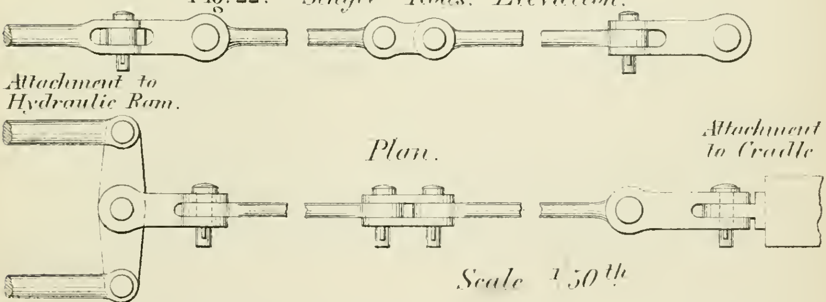


Fig. 22. *Single Rods. Elevation.*



Scale 1/50th.

Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 Feet

Institution of Mechanical Engineers.

PROCEEDINGS.

October 1881.

The Autumn Meeting of the Institution was held in the Memorial Hall, Albert Square, Manchester, on Friday, 28th October, 1881, at Three o'clock, p.m.; Edward A. Cowper, Esq., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed.

The President said he could not sign the minutes without expressing his great satisfaction that the Newcastle meeting had been such a successful one. The kindness and hospitality of their friends in Newcastle had certainly been most pleasing, and he trusted that in every town the Institution might go to they would be received in like manner. Their next summer meeting would be held in Leeds, the Council having accepted a most cordial invitation from the engineers of that town, and he believed it would be equally successful. He might say that a strong Committee had already been formed there, and they were at work getting matters together—arranging for papers, looking out for interesting facts, &c. The Chairman of the Committee was Mr. James Kitson, Jun., and among the members were Mr. David Greig, Mr. J. Hawthorn Kitson, Mr. Joseph Craven, Mr. Henry Davey, Mr. Arthur Greenwood, Mr. Benjamin Walker, Mr. Edwin Wardle, Mr. James Young, and others; while the Honorary Secretaries were Mr. J. Hartley Wicksteed and Mr. John Barber, of whom the latter had already acted in the same capacity for the Iron and Steel Institute in 1876.

The President announced that the Ballot Lists for the election of Members had been opened by a Committee of the Council, and that the following New Members &c. were found to be duly elected:—

MEMBERS.

Joseph Liddell Anderson, ...	London.
William Bawden, ...	Manchester.
William Bocquet, ...	Lahore, India.
John Henry Briggs, ...	Kimberley, South Africa.
Robert Briggs, ...	Philadelphia.
Henry Wheeler Bulkley, ...	New York.
Robert Scott Burn, ...	Stockport.
Henry Woodham Dunn, ...	Knysna, Cape Colony.
Sidney Howard Farrar, ...	Port Elizabeth, S. Africa.
Edward William Mackenzie Hughes, .	Adamwahan, India.
Arthur Laing, ...	Sunderland.
George Benjamin Mallory, ...	New York.
Josiah McGregor, ...	London.
Charles Scott Meik, ...	Edinburgh.
Arthur Nesfield, ...	Liverpool.
Henry Parry, ...	Newcastle on-Tyne.
George Richardson, ...	Oldham.
George Innes Scott, ...	Newcastle-on-Tyne.
Joshua Shaw, ...	Manchester.
Henry Smith, ...	London.
William Augustus Wharton, . . .	Nottingham.
John Wilson, ...	London.
John Mervyn Wrench, ...	Lahore, India.
Robert Younger, ...	Newcastle-on-Tyne.

GRADUATE.

William St. John Oswell, ...	London.

The President announced that the President, two Vice-Presidents, and five Members of Council, would go out of office at the ensuing Annual General Meeting, according to the Rules of the Institution; and that the list of those retiring was as follows:—

PRESIDENT.

Edward A. Cowper, ...	London.

VICE-PRESIDENTS.

I. Lowthian Bell, F.R.S.,.	Northallerton.
Charles P. Stewart, ...	Sunninghill.

MEMBERS OF COUNCIL.

William Anderson, ...	London.
Thomas R. Crampton, ...	London.
Edward Easton, ...	London.
John Penn, ...	London.
William Richardson, ...	Oldham.

The whole of the retiring Vice-Presidents and Members of Council offered themselves for re-election; and he was happy to say that their most important officer, whose name had been mentioned at the last meeting, and who was now to be formally nominated at this meeting, had accepted the nomination. He referred to Mr. Westmacott, and he felt sure that no gentleman could fill the post of President with greater satisfaction to the members. He should himself vacate the chair with less feeling of regret, because he knew it would be better filled by that gentleman than it had been by himself. The following additional candidates were now nominated by the Council for the election at the Annual General Meeting :—

Election as Member.	PRESIDENT.	
1862.	Percy G. B. Westmacott, . . .	Newcastle-on-Tyne.
	VICE-PRESIDENT.	
1859.	George B. Rennie, ...	London.
	MEMBERS OF COUNCIL.	
1865.	Francis C. Marshall,. . . .	Newcastle-on-Tyne.
1866.	Henry Chapman, ...	London.
1866.	E. Windsor Richards, . . .	Middlesbrough.
1867.	Ralph H. Tweddell, ...	London.
1879.	William Parker, ...	London.

According to the Rules of the Institution, it was now open to any Member to add to the list of candidates.

No other names being added, the President declared the above list to be complete.

The President reminded the Meeting that, if any Member had any motion to propose at the Annual General Meeting, in reference to the Bye-Laws, notice must be given of it at the present meeting.

No such notice was given.

The following papers were then read and discussed by the Meeting:—

On Bessemer Steel Plant, with special reference to the Erimus Works; by Mr. C. J. Copeland, of Barrow-in-Furness.

On Compressed-Air Engines for Tramways; by Mr. W. D. Scott-Moncrieff, of London.

On the motion of the President, a vote of thanks was passed to each of the authors for his valuable paper.

The President announced that four Telescopic Gasholders, erected for the Corporation of Manchester at their new Gas Works, Bradford Road, Manchester, would be shown on the following morning to the Members. Three of these gasholders were already filled with gas, and it was intended to fill the fourth during the visit of the Members, that they might have the opportunity of witnessing the operation. The gasholders were 150 ft. diameter, and 105 ft. high, in three lifts; and would be found well worthy of inspection. They had been erected by the Horseley Iron Co., the engineer being Mr. J. G. Lynde, M. Inst. M. E., by whose kindness the visit had been arranged.

The Meeting then terminated.

ON BESSEMER STEEL PLANT, WITH SPECIAL REFERENCE TO THE ERIMUS WORKS.

By Mr. C. J. COPELAND, of Barrow-in-Furness.

The Bessemer Steel-making Plant at the Erimus Works, Middlesbrough, designed by Mr. Samuel Godfrey, has perhaps a special interest as affording an example of the conversion of ironworks into steelworks. The Erimus Works were originally designed for the Danks process, and the steel plant has been necessarily introduced in a comparatively limited space.

The cupola stage A, Fig. 1, Plate 85, and the cupolas C for melting the pig iron, remain as they were, and the wall B of the new converter house leaves them outside the building. The elevation of these cupolas, as constructed for the Danks process, not being sufficient to run the metal direct into the converter, it is run into a receiver D, and from thence tapped into the ladle E on the table of the hydraulic lift F, Figs. 1 and 2, Plates 85 and 86. This lift has a ram 14 in. diameter and 21 ft. 6 in. stroke. The table is made sufficiently strong for a locomotive to run over it, when it is at the ground level. The lift is worked by an ordinary slide-valve, levers for which are placed both on the platform G and on the floor-level; and there is a knock-off arrangement at the top and bottom of the stroke. There are two guide-pillars, which are also used for supporting the platform G.

The metal ladles E have a capacity of six tons, with an ample allowance for slag; being made to tap at bottom, they have no tipping gear attached to them. They are supported on their carriage by an angle-iron belt, and are easily removed for relining and repairs. The metal runner H is suspended in a movable sling at the outer end, and supported on wheels at the back end: it is easily adjusted to the spout on the metal ladles and to the mouths of the converters K.

The spiegel cupolas M, Plates 85 and 86, are 4 ft. 4 in. diameter inside the shell, and are placed on the platform G, one on each side of the lift F. The spiegel is run into small ladles L, which are lifted by the hydraulic crane N attached to the wall of the house: it is weighed, in the act of running from the cupolas, by one of Duckham's hydraulic weighing machines suspended to the jib. The metal in the ladles is then tipped into the runner H. The valve-gear for the crane N is fixed on the platform G.

The converters K, two in number, have wrought-iron shells, 8 ft. diameter outside, and $\frac{7}{8}$ in. thick. The length from the centre of the trunnion to the top of the nose is 8 ft. 8 in.; and to the bottom of the converter, exclusive of blast box, 5 ft. 10 in. The shells are carried by a strong cast-iron belt, 3 ft. deep, a portion of which is used for conveying the blast. The trunnions are 19 in. diameter, and are cast on the belt, which is made in segments, and is fitted to the converter between strong angle-iron rings, so that it can be removed without damaging the shell of the converter.

A special feature of the converter is the cast-iron hood fixed on the back above the belt, to form a tapping hole J, as shown enlarged in Fig. 4, Plate 87. By this means, should any difficulty arise through the metal taking up phosphorus from the slag, when it is being poured in the ordinary way, it can be tapped out, with the converter in an horizontal position, from beneath the slag, as shown at J in Fig. 3.

The converters are carried on cast-iron standards P, Plate 85, the bases of which are on the floor level, 15 ft. 6 in. from the centre of the trunnions. These standards are tied to the walls of the house, and secured together by the platform girders. The tipping gear T, Plate 86, is carried on brackets attached to the outer standards, and consists of movable horizontal hydraulic cylinders, on which are fixed cast-steel racks, working in steel pinions keyed on the converter trunnions. The piston-rods are of Siemens steel, and are bored out so as to conduct the pressure to each side of the pistons. The outer ends of the piston-rods are secured to the standards P, and the cylinders have sufficient travel to turn the converters through three-fourths of a revolution.

Hand-cranes Q, Plate 86, are fixed on each side of the platform G, for lifting the blast-box covers, &c.; and jack rams are provided for changing the bottoms.

The centre casting-crane R, Plates 85 and 86, has a ram 2 ft. diameter and 36 ft. long, the working stroke being 19 ft. The extreme radius of the ladle is 17 ft., with a traverse inwards of 18 in. The jib is turned, and the ladle traversed, by hand-gear; the centre casting having a steel pivot at the top, and being fitted with a ring of live rollers at the bottom. The great length of lift was arranged specially for the dephosphorising process, and the proposed operations with that process are indicated in Fig. 3, Plate 87. The dotted lines show the crane at its extreme lift, transferring the desiliconised metal to the second converter; which may be found necessary, if the operation cannot be completed in the ordinary way.

The ingot cranes S, Plate 85, two in number, are of the ordinary type, having rams 10 in. and 15 in. diameter, and a working radius of 18 ft., with a lift of 7 ft. 6 in., as shown to a larger scale in Fig. 10, Plate 89. The objection urged against this kind of crane is that the dead weight of the ram and jib is greater than the live weight the crane will lift; but, having regard to the great desideratum of all steel plant, namely simplicity, the author thinks that this objection may be disregarded. The jibs are fitted with the usual racking-out gear, and the cranes are made for a lift of five tons.

The low level of the Erimus Works necessitated special arrangements being made for draining the crane and hydraulic lift pits. This is accomplished as follows. The top supporting plates of the cranes are bedded in cement over the pits, so as to form an air-tight joint. Two-inch drain pipes are carried to the bottom of the pits, and a pipe from the blast main is introduced at the top, thus forcing the water up into the culverts provided for the surface drainage.

The accumulator has a ram 2 ft. diameter, with a stroke of 20 ft., and is weighted to give a pressure of 400 lbs. per sq. in. The ballast box surrounds the cylinder, and is hung from a crosshead. The accumulator is fitted with a relief valve, and has knock-off gear attached to it, for stopping the engines when the accumulator is at the top of its stroke.

The horizontal hydraulic pumping engines were supplied by Messrs. Davy Brothers. The steam cylinders are 18 in. diameter and 30 in. stroke. The piston-rods, which are of steel, pass through the back ends of the cylinders to work the double-acting pumps, which are placed directly behind them. The pump pistons or buckets are $6\frac{1}{2}$ in. diameter, and the rams $4\frac{5}{8}$ in. diameter. The valves are placed at one side of the pump barrels, and are arranged for the delivery of water on both the in and out strokes of the pistons.

The blowing engines, supplied by Messrs. Tannett Walker and Co., are of the vertical compound type, with steam cylinders 42 in. and 78 in. diam., and air-cylinders 54 in. diam., with 5 ft. stroke, Fig. 12, Plate 89. They were fully described by Mr. Walker in a recent paper read before the Institution of Civil Engineers. (Proceedings, vol. lxiii., p. 9.)

The blast and water pressure are led to a distributing box, having a platform over it, on which is arranged a series of levers for working the valves. The blast is carried from the box to the lime-infuser in a single 18 in. main; although there are two blast-valves on the distributing box, one for each converter. On the other side of the lime-infuser the main is divided into two 12 in. pipes, on each of which there is a sluice valve. To prevent the possibility of the converters being turned up with these sluice valves shut, there is a small hydraulic cylinder fixed over each to work it, and the valves for starting these are on the distributing box. The levers for working the hydraulic valves have a cross-bar attached to them, which comes in front of the blast-valve lever; so that the act of opening the blast-valve would work the hydraulic valve, should the attendant forget to do so.

As the lime-infuser is perhaps somewhat of a novelty, a vertical section of it is shown in Fig. 5, Plate 87. It consists of a wrought-iron casing A, 5 ft. diam. and 10 ft. high, placed on a cast-iron base or hopper B. The charging door C on the top is on a level with the converter platform; and there is also a blast connection D for admitting the pressure into the top of the infuser when charged. At the bottom of the hopper there is a cylindrical case containing a worm E, which is driven by a small pair of engines, and this conveys the lime to the blast main.

The blast for the cupolas is supplied by three Root's blowers; and the steam for the Bessemer plant comes from eight Lancashire boilers, by Mr. Joseph Adamson, 30 ft. long by 7 ft. diam., with two 2 ft. 9 in. flues in each, and working at a pressure of 70 lbs. per sq. in.

Having thus given a short description of the Erimus plant, the author now proposes to notice one or two of the recent systems which have been brought to a practical test in connection with steel making.

The first of these is Mr. A. L. Holley's system of changing the converters without disturbing the belt or trunnions—a great advantage when basic linings are used, which require frequent repair. It will be seen from Figs. 6 and 7, Plate 87, that it consists in lowering the converter K out of the belt B by means of a hydraulic lift L, on which there is a bogie A. The converter rests on this bogie, and is carried away upon it. The shell of the converter is secured to the belt B by wrought-iron knees and cotters C, Fig. 6, which are slacked back when it is to be changed; and there are also knees D for supporting the converter on the bogie, Fig. 7. This method of removing the converters obviates the necessity for an overhead crane, which, when made to lift a 10-ton converter, is a costly and often inconvenient appliance.

Messrs. Thomas and Gilchrist propose to overcome the necessity for removing the converters by means of a special mixture for relining, which is thrown or poured in round an iron shell or mould fixed inside the converter. This mould is made to collapse, so as to be easily removed when the lining is finished.

Another invention which may be noticed, although not of such recent date as the above, is Mr. Arthur Cooper's method of utilising the waste heat from the converters, where the direct process is not in use, and the pig-iron has therefore to be remelted. On this method the flame from the mouth of the converter passes into a chamber filled with pipes; and through these pipes the blast for the cupolas passes, the chamber being so arranged as to prevent the flame from playing direct on the pipes. The temperature of the blast is raised by this means to between 400° and 500° Fahr. At Messrs. Brown

Bayley and Dixon's Works, Sheffield, where this system is adopted, it has effected a saving of 25 per cent. in the quantity of coke used for melting the pig-iron.

Before closing this paper, the author would suggest the adoption of a marine type of boiler, as a means of effecting a saving, both in the space occupied and in the consumption of fuel. The author's firm are now making such a boiler for the Barrow Steel Co., and on their recommendation Mr. H. Turner's system has been adopted, Figs. 8 and 9, Plate 88. This boiler, occupying a space of 9 ft. by 21 ft., has a grate surface of $32\frac{1}{2}$ sq. ft., and a total heating surface of 1275 sq. ft. A Lancashire boiler of the ordinary type, 30 ft. long by 7 ft. diam., with two flues 2 ft. 9 in. diam., has a grate surface of say 40 sq. ft., and a heating surface of 600 sq. ft. only. The marine boiler thus has more than twice the heating surface at about one-third extra cost; and it is expected that it will effect a saving of at least 1 lb. of coal per I.H.P. per hour.

Discussion on Erimus Steel Plant.

Mr. Copeland wished to add that the spiegel crane, shown at N in Plate 85, had been disused since the works were started, now three months ago. It had been found more convenient to deal with the spiegel metal in the usual way, and to run it direct into the trough H. The crane was therefore not necessary, at least so long as they were working, as at present, with the acid process, using hæmatite pig, and not with the basic process.

Mr. Benjamin Walker said the paper, in referring to the ingot cranes, p. 629, stated that the system adopted had a certain amount

of simplicity about it, which recommended it. But from the section of the ingot crane given in Plate 89, Fig. 10, it would be seen that there was a large gland at the bottom and another at the top. Referring to the crane which he presumed was intended to be compared with it—a crane of which his own firm had made a great many—it would be found that there were only two glands, and that both were in sight, the middle ram of the three being only used as a guide for the crane. The gland below ground, as in Fig. 10, was undesirable, because it was not easily seen and repaired when it leaked. Taking the diameters of the ram, as given in the paper, at 15 and 10 in., and the pressure at 600 lbs. per sq. in., this would give a total lifting power to the crane of 26·3 tons. The paper did not give the weight of the moving parts of the crane, but this would be about 10 tons, and therefore the available force in the vertical direction was not less than 16 tons. He need not point out that, if that crane were hooked on to a light load, say 4 or 5 tons, and it went on lifting without a check, destruction would be sure to take place. Now out of a hundred lifts in a Bessemer pit not more than one would be above 3 tons, viz. when they changed the ladle, when it was about 5 tons; and therefore the crane shown by the author used a force of 16 tons, when 5 tons would always be sufficient. Another consequence of having that system of ram was that there was a part of the barrel or central pillar which was very small, being only about 10 in. in diameter; and that really was the measure of the strength of the crane.

A third form of crane, represented in Fig. 11, Plate 89, had been referred to by Mr. Menelaus at a recent meeting of the Iron and Steel Institute (Journal, 1881, p. 161). His own firm had made for Mr. Menelaus two of those cranes, about a year and a half ago, and some difficulty arose in consequence of their having misunderstood the amount of pressure required. Having found out the mistake, they made arrangements by which the difficulty was got over; and the best evidence that Mr. Menelaus approved of the style of crane was that he had since ordered two others. When a crane was made on that principle, the central ram was placed in constant communication with the accumulator. The upward pressure on that ram was about

9 tons, and the crane weighed altogether about 12 tons. Hence, if the water were let out of the other two rams, the crane would of course go down with a force of about 3 tons. The smaller rams had together an upward pressure of 6 tons, so that they were able to lift this 3 tons, and also the weight of the ingot, and therefore the crane worked all day long with a power represented by 6 tons, instead of 26 tons as in the crane described in the paper. There was also the advantage that the barrel of the crane could be made stronger, so that it was less liable to be broken. His own preference was at present for the type of ingot-crane where the barrel was plain, and there were two sets of rams, one in constant communication with the accumulator and nearly balancing the weight of the crane itself, and the other under the ready command of the workman for lifting the load. But his firm were now making another system of crane, which he hoped to have the honour of showing to the members in Leeds at their next summer meeting. It would use less water, and he thought it would be altogether better than anything they had made before. And, as the President had referred to the intended meeting at Leeds, he might mention that they were making very great efforts, and that those who did not go there would miss a great treat.

With regard to the blowing engines referred to in the paper, he might mention that since his description of them before the Institution of Civil Engineers they had been put to work. There was one point to which he desired again to refer—namely the advantage of using compound engines, where economy was of any importance, instead of the ordinary non-compound engine. He had taken diagrams in cases where there was no expansion, and the cylinders were altogether unlagged or unclothed. Those diagrams showed that the steam entered the cylinder at about 5 or 6 lbs. less pressure than it had in the boiler. Now the first element in economy was to get the full boiler-pressure into the steam cylinder. No economy practically could be got out of the steam engine itself, except by the expansion of the steam. In the case of the blowing engines referred to, Fig. 12, Plate 89, the steam passed into the high-pressure cylinder at about 60 lbs. pressure, and came out of

the low-pressure cylinder at about 5 lbs. above the atmosphere. That degree of expansion was very difficult to get; he had never been able to do it before, and he had never seen it in any other engine. Suppose there was a boiler pressure of 80 lbs., then with the ordinary proportions of high-pressure engines they could not get the steam at much more than 45 lbs. pressure into the cylinder. Suppose the cut-off was in the middle of the stroke, and the steam exhausted into the atmosphere. From the average of a very large number of diagrams taken by himself from high-pressure engines—some taken from Mr. Adamson's engines, who had made a great number of engines of a very excellent type—he had found that the steam went into the cylinder at about 40 lbs. pressure, and into the atmosphere at about 22 lbs. pressure. He need not say that that was a very wasteful way of using steam.

His firm were now making for MM. de Wendel & Co., of Hayange and Jœuf, some blowing engines which he believed would be much more economical than anything that had hitherto been made; and several others were also on order. These engines would work at 110 lbs. pressure of steam, would use surface condensers, and would drive the air and circulating pumps by a separate engine; and they would have expansion-valves in both the high and the low-pressure cylinder. The engines were constructed to work at as low a boiler pressure as 60 lbs. per. sq. in. above the atmosphere. Taking the initial pressure in the high-pressure cylinder at 72 lbs. absolute, there would be twelve grades of expansion, the steam going into the condenser at 6 lbs. pressure above zero.

In the engines shown, Fig. 12, Plate 89, the cranks were not quite at right angles; the crank of the low-pressure cylinder led in the ordinary way, so that the mouth of that cylinder was open to receive the steam as it came out of the high-pressure cylinder. He was perfectly aware however of the economy of the system, originally proposed by the President, of introducing between the high and the low-pressure cylinder a receiver heated with steam; and in the engines making for MM. de Wendel he was going to adopt that plan, and introduce between the high and low-pressure cylinders what was commonly called a "Cowper's hot-pot." In the engines

shown the areas of the cylinders were as $3\frac{1}{2}$ to 1. These engines would work very economically if they were condensing; but they were non-condensing. According to his experience the results of the compound system were different when it was applied to a blowing engine, from what they were in the case of a mill engine. When applied to a blowing engine it would save, as compared with a non-compound engine, one-third of the coal. It would be seen by Fig. 12 that the low-pressure cylinder was jacketed, and that the jacket was made in two half lengths, united in the middle of the cylinder. If a jacket were cast on in the old way, all in a single length, and were made of very strong metal, it was liable to crack in cooling. Hence for the Admiralty it was a universal plan to put the jacket on loose. But by the system shown it could be made of very hard metal, because the contraction lengthwise would be less, being only that due to half the length of the cylinder; or it might be divided again if thought desirable. On the old plan, even if the workman was told to use good hard metal, he was so afraid of contraction as to be tempted to use soft metal for his own protection.

The paper referred to the system proposed by Mr. Holley for changing the converters. He had himself had a good deal of experience in converter work, and he did not think it was likely to be widely adopted. When engineers had to deal with a thing weighing about 80 tons, they were not in a great hurry to remove it, but were more disposed to try and patch it up in place. Moreover, from the experience that had now been gained with the Thomas and Gilchrist process, there would be little more difficulty, so far as the lining was concerned, than with the old process. MM. de Wendel lined mainly with lime bricks, and found no difficulty with the lining. The system of placing a good number of converters side by side, and all alike, was in his own opinion the best. There should be plenty of converters, and then, if one of them got wrong, they could easily repair it and go on with the others.

The President asked if Mr. Walker could describe the mode of ramming up the bottoms to the converters, with refractory material mixed with a little tar, as now used in Germany.

Mr. Walker said that Messrs. Bolckow Vaughan and Co. were using the same process, and in many cases it answered very well. Instead of the usual fire-clay pipes, surrounded by ganister, in the bottom of the converter, a number of rods were planted in the bottom, and the lining rammed round them; and then the rods were withdrawn, leaving holes for the blast. The black lining was common lime mixed with tar, instead of the ordinary ganister used with hæmatite.

At the end of the paper there was a remark about the introduction of a marine type of boiler for steel works. In his opinion it would be altogether wrong, in cases where space was of no moment or not of much moment, to give up the old-fashioned Lancashire or Cornish boiler. It was impossible to have a boiler with a number of tubes, without a great deal more wear and tear, and a much more complicated arrangement, than with the old-fashioned boiler. The result of his experience in boilers was that it was best to have a single corrugated flue, making it as large as possible, so as to get a large body of fire; and the plainer the boiler was, the better. The great curse of the country had been that boilers had been made at too low a price. In the discussion on the quadruple engine, he had given it as his opinion (Journal of the Iron and Steel Institute, 1875, p. 476) that one half the engines and boilers in the country might be taken out and replaced, with a saving of more than 15 per cent. on the outlay.

Mr. Daniel Adamson would not have risen to speak, but for the fact that his name had been mentioned by the last speaker; who ought to have added to the information which he gave the fact that the engines alluded to were adapted for a boiler pressure of only about 50 lbs., so that if they had been put to work at much above 40 lbs. it would have been a bad job for the user. He was glad to find that the piston-valve, introduced by himself, had been adopted by Mr. Walker, as shown in Fig. 12, Plate 89. Its introduction was in some respects unfortunate to himself, for when he built the Bessemer steel works at Penistone he got into great disgrace with Sir Henry Bessemer by introducing the piston-valve; subsequently however his piston-valve had become the standard one for the air cylinders of Bessemer blowing engines.

He was glad that the members had heard Mr. Walker's views about hydraulic cranes, because he had been one of the largest makers of them. He himself had also had a considerable experience in their manufacture and use; and he took somewhat the view of the author, that simplicity was of very great importance. If, instead of having the dead-weight lifting ram, a ram with an annular space were used, with a water-tank tower, and the dead-weight resistance were thrown back into the tower, they would then accomplish with a simple crane all that could be got out of the dead-weight lifting ram crane, as the work done by the descending dead weight of the crane would be again used to assist the pumping power. If there were no such system, and the water was merely discharged from the crane at the ground level, the dead-weight lifting ram would save pressure-water commensurate with the dead load that was upon it, and there would be an economy of water power.

He thought the author of the paper showed great courage in stating that the marine type of boiler was going to save 1 lb. of coal per I.H.P. per hour. A first-class mill engine only used from 2 to 2½ lbs.; so that it was clear that the boiler referred to must save nearly 50 per cent. That was a most extraordinary result to follow from merely a slight increase of surface. In respect to the Lancashire boiler, he ought to correct a serious mistake made by the author on p. 632. Its heating surface, for the size of boiler there given, was not 600 sq. ft., but 840 sq. ft.; and instead of a grate surface of 40 sq. ft., it was usually worked in the Lancashire district with a grate surface of 33 sq. ft. On that basis the Lancashire boiler had about 14 sq. ft. heating surface per H.P., and 0·55 sq. ft. grate surface per H.P. The author was thus going to obtain this wonderful result with a grate surface of 32½ sq. ft., or ½ sq. ft. less than that of the Lancashire boiler. Now, if he had a smaller grate, and could therefore generate a less quantity of heat, how was he subsequently to gather heat out of nothing and save 50 per cent.? The thing was impossible. If he wanted to do more work, he must have grate surface commensurate; and then it was still a question whether the heating surface of the tubular boiler was really the better of the two. The impurities from the fire, wet coal, negligent

firing, and so on, would all contribute to choke up the tubes and reduce their heat-conducting power. The same did not apply to the Lancashire boiler, because any soot or dirt adhering to the flue was burned off again by the intensity of the fire itself. In cases where the marine boiler had been adopted for stationary purposes, the evaporative power was so reduced, first from the bad conducting power of the soot, and secondly from the smaller area of smoke-way, that, instead of better results being obtained, they could not get as good results with the same amount of fuel. With a very large heating surface, as in the marine type of boiler, a forced draught was needed to bring up the intensity of combustion, as in a locomotive. The locomotive, when it was standing still, was a very useless steam-generator, and a very bad evaporator; but when it was at full speed, and thus sending a tremendous current of air through the fire-box, a great deal of water was evaporated, and all the heating surface was turned to account.

With regard to the cost, according to his view and according to the Board of Trade conditions, it was necessary to allow 20 sq. ft. of heating surface per H.P. in the marine type of boiler, against 14 sq. ft., as previously named, in the Lancashire boiler. On that basis the marine boiler described on p. 632 had only 63¾ H.P., as against the 60 H.P. for the Lancashire boiler compared with it. But it was said that the cost of the former was a third more than that of the latter. That was a very unfortunate condition of things for the more expensive structure. He should altogether condemn the application, for ordinary purposes, of the complex marine boiler, not only on the grounds he had stated, but because of the great variation in the water available throughout the various geological areas of the country. There were some waters that were very dangerous to use, from sediment or chemical composition; and hence there were very few places in the kingdom where a marine boiler could be always used with safety; while without an enormous chimney its large heating surface could not be brought to bear.

Mr. Charles Cochrane said it seemed to him that they had been landed in a discussion, not upon the question of steel-making, but upon the respective merits of boilers; and he could not help saying that one class of boiler, suitable for iron or steel works, had been altogether ignored, namely the Root water-tube boiler. Whatever advantages a marine boiler might possess, in regard to the use of tubes internally heated, the simple expedient of making the tubes contain the water, and heating them outside, would get rid of all the liability to explosion, which necessarily attached to the marine class of boiler as well as to the Lancashire boiler. Some years ago (Proceedings 1871, p. 229) he had given a description of the boiler to which he referred, and it had since increased in favour with his firm; indeed they now had no other boilers than the Root water-tube boilers at the Ormesby Iron Works, for their blast-furnace arrangements. But, whatever class of boiler was used, it appeared to him that Mr. Strong's purifier (Proceedings 1881, p. 539) would deliver the water in a pure state, and so get rid of all the difficulty with regard to bad water referred to by Mr. Adamson.

Mr. T. R. Crampton thought the time had nearly come when they ought to ignore the difficulty arising from impure water. There were sufficient appliances by which the water could be made good. It was always an economy to have it pure; and if persons would only take the trouble and go to the expense, almost any kind of water and boiler might be used.

Mr. Jeremiah Head observed that the paper had a special interest as affording an example of the conversion of ironworks into steelworks; and that perhaps was a line which ought to be followed out in the discussion. The Erimus Iron Works, as they were formerly called, were situated near Stockton-on-Tees, and had been put up to work the Danks process of puddling. That was a failure, and therefore the works had been standing still for several years. Those who lived in the locality were much gratified to find that they were now going, and turning out a produce of something between 600 and 700 tons of steel rails per week. That was one of the examples of a great change that

had been going on in the metallurgy of the country; and it was gradually becoming more and more easy to carry out that change. The works mentioned were not working the basic process at all, but the acid process, and for that purpose they were obliged to have hæmatite pig iron. Several years ago it would have been impossible for them to get the hæmatite pig iron without going to Cumberland for it; but now, owing to the importation of Spanish ore into the Cleveland district, there were something like thirty blast furnaces making hæmatite iron in the North Eastern district. That rendered it possible for works of this sort to make the rails by the acid process at a profit, while it would have been quite impossible to do so some years since. But they were also looking forward to the time when the basic process might even supersede the acid process.

It was a curious thing that, whereas the Cleveland district, by which he meant the county of Durham and North Yorkshire, used to roll a large proportion of the iron rails made in the whole of the country, there were now hardly any iron rails made there at all, but all were made of steel. Several years ago there were no steelworks of any sort, except those at Wolsingham in the county of Durham. Now he believed there were eight steelworks in the county of Durham and North Yorkshire, exclusively occupied in making steel rails and steel castings.

Of course steel makers were looking forward to supersede the makers of iron, who now mainly existed to manufacture iron for boilers, for shipbuilding, and for general merchant purposes. Notwithstanding that rails were now entirely, or almost entirely, made of steel, there was still as large a quantity of iron made as ever there had been. Including bars and angles, there were about 600,000 tons of iron made every year in the North Eastern district. The question was, when would that iron be superseded by steel, and in what way. Of course the great bulk of it went for shipbuilding purposes; and as yet for shipbuilding purposes the steel made by the Siemens process was almost the only steel which was used. One of the eight steelworks which he had mentioned was however that of the the North Eastern Steel Company, now being built at Middlesbrough, and was intended to make tyres, blooms, and ingots, by the Bessemer

basic process, to be finished up in the different ironworks; and in that way if possible to forward the change from iron to steel, which many persons believed was impending. For the present he thought that iron shipbuilding would be mainly carried on in the North Eastern district, and steel shipbuilding at Glasgow, where steel was largely made by the Siemens process. If all the ironworks now in the Cleveland district were gradually to be turned into steelworks, it was probable that they would still have to use Cleveland iron, and, as far as he knew at present, they would have to adopt the basic process. That process was believed to be fully worked out as far as the mechanical and chemical arrangements were concerned, but the commercial arrangements had not been very fully worked out: at all events, if they had been, they had not been made public. These were considerations which might not be out of place, as connected with the conversion of ironworks into steelworks in the North of England.

Mr. I. Lowthian Bell said Mr. Head appeared to congratulate himself that those ironworks which might fall into desuetude, on account of iron being superseded by steel, had yet a glorious future before them, owing to the ease with which it was possible to convert an iron rolling-mill into a steel rolling-mill. He feared however there was a great fallacy in that view. He did not himself know of many cases where an iron rail-rolling mill had been profitably applied to the rolling of steel. They had not far to go to see the reason. Iron was rolled at a high temperature; it must have a welding heat. But it was very different with steel, for the colder steel was rolled, within limits, the better; and hence it required a much greater power proportionately to roll it. At one of the ironworks at Darlington, where an iron-rail mill had recently been converted into a steel mill, having all the known improvements, the results had not been satisfactory so far as the stability of the machinery was concerned.

With regard to the supersession of the acid process by the basic, that must depend in each case on the relative cost of hæmatite iron and common iron. In Germany, where the cost of making hæmatite

iron—that is, iron sufficiently free from phosphorus to be treated by the acid process—was much higher than the cost of iron which required treatment by the basic process, they had no difficulty in deciding; but the matter became more complicated, when the difference between the cost of one pig-iron and the other was so small as it was in some places. He agreed however with Mr. Head that in all probability the basic mode of manufacture would be gradually extended; indeed, he was not quite sure whether, even when it was wished to produce a substance equivalent to malleable iron so far as its chemical constitution was concerned, the pneumatic process in some form or other would not soon prove the easiest way of producing it. It was clear that all that was required, in converting cast iron into malleable iron, was the freeing of the cast iron from its associated impurities—carbon, silicon, and phosphorus. Whether this was done in one way or another might probably be found to be a matter of indifference. It was clear that the exposure of the iron to a deoxidising influence could not be so rapidly and therefore so economically done in a puddling furnace, as it could be in a Bessemer converter.

With regard to what had fallen from Mr. Cochrane about the advantages of the Root boiler, he was afraid there were great diversities of opinion in Cleveland on that subject. His own firm used the simplest possible kind of boiler, one which might, no doubt, after what they had heard to-day, be called a somewhat unphilosophical sort of boiler. It was a plain cylindrical boiler, of 75 ft. total length, but divided into two half lengths, communicating by a U tube placed vertically, which prevented all difficulty in connection with the curvature of the boiler when unequally heated. Such boilers had a great advantage in sending away the products of combustion cooled down to an extent rarely attained in boilers in that district. Of course in every boiler it was of the utmost importance to deprive the escaping gases of as much heat as possible before they went up the chimney. That was of greatly increased importance at his own works, because they were there using a gaseous fuel, with probably 70 per cent. of inert matter in the form of nitrogen &c. No heating effect from combustion was produced by that matter, and therefore it became

essential to retain the products of combustion as long as possible in contact with the boiler. They had found the long boiler system to be a very economical one. He was afraid that in the Root boiler, however great the heating surface might be, the distance between the fireplace and the chimney was so short that there must inevitably be an enormous loss of heat. He very much questioned whether such boilers worked more economically than those he referred to. They were working at the Clarence Iron Works, Middlesbrough, with high pressure and no condensation in the engines; and yet the blast furnaces were quite able to heat all the blast, raise all the steam, and have a good deal to spare.

The temperature of the products of combustion escaping from the long boilers of course varied a good deal, but the limits would be between 500° and 800° Fahr. Just after the boilers had been cleaned, so that the actual surface of the iron was exposed to the gases, the absorption of heat was very rapid and complete; in fact they scarcely let more heat go up the chimney than was required for the production of the draught itself. There was a great fallacy often entertained in connection with the temperature at which gases escaped: namely that the hotter the gas going into the chimney, the more powerful would be the draught. But M. Peclet had demonstrated, in practice as well as on mathematical grounds, that a temperature of about 500° Fahr. was that which gave a maximum draught. The boilers afterwards got coated with what in the Cleveland district was called "fume," which was a very bad conductor of heat; and then the temperature of the chimney gases rose to 700° or 800°, and sometimes to a red heat. But, as a rule, at the end of the flues, where the gases left the boiler, there was no sign of redness at all.

Mr. P. D. Bennett said Mr. Walker, in the course of his remarks, threw out the idea that the better the quality of cast iron, the more likely it was to crack in cooling. During an experience of many years in connection with castings, he (Mr. Bennett) had found an entirely opposite result. In making castings, unless when he was driven sometimes to use, for special reasons, slightly inferior qualities

of metal, he preferred to resort to the very best qualities he could get. The best qualities made the best castings; and the better the quality, the less liable it was to crack.

Mr. Walker asked permission to add a few words in explanation. Some few years ago he was called upon to make some very large valves for letting water out of some docks. They were to be made of the best metal, namely Blaenavon, Pontypool, and a cold-blast Staffordshire pig; but, when the work was undertaken, he pointed out that large flat surfaces of such metal were very likely to crack. The mixture was tried however, the cost being a matter of no moment; but the attempt was unsuccessful. He then made another attempt, but he used three of the softest Scotch pigs he could get; and the valves so made were at work to the present day. A high quality of hard cylinder metal was very much more likely to crack by contraction, when there was a draw upon it, than soft metal was. As a girder, or to carry a load, the better the metal the more it would carry; but his experience certainly was that high qualities of cold-blast iron were very liable to crack.

The President wished to add one or two words with regard to the discussion upon tubular boilers, as against Lancashire or Cornish boilers. There were two points to guide an engineer as to whether he would use a multitubular boiler, or a single or double-flued boiler. The first question was whether he wished to have a quiet, safe, comfortably-working boiler, that would not frighten anybody by the water running low; and the next was whether he meant to take the trouble to clean out the tubes often; because, if he did not, he had better not have a multitubular boiler at all. There were many of that class which were working satisfactorily; but for a thoroughly good working servant he preferred the Lancashire boiler.

With regard to the power required for rolling iron and steel, some experiments had been recently made in Germany (Proc. Inst. C. E., vol. lxv., p. 441), from which it appeared that it took three times the power to roll steel that it did to roll the same section in iron, thus confirming Mr. Bell's views. Reference had been made to

the new steel works that were being put up for various purposes; and at the risk of repeating an old observation, he desired to take the opportunity of saying a word again in favour of steel sleepers. The substitution of steel for iron was good; but the substitution of steel for wood was still better. If, instead of paying for wood sleepers from abroad as they had done, Englishmen made the sleepers themselves, the demand for steel would be doubled and better sleepers would be made; they would last longer and give more satisfaction. Some 70,000 tons of iron and steel sleepers had been used in Germany; and he did not see why the same thing could not be done in England. Longitudinal sleepers had been extensively tried, but cross sleepers were preferred; they were the cheapest and lasted the longest.

Mr. Copeland, in reply, said Mr. Walker appeared to think that the paper had referred only to his own crane in speaking of the advantages of simplicity; but it referred in reality to two or three different kinds of crane. There was one point however to which he desired to refer, bearing on the question of the undoubtedly economical three-cylinder cranes. Take the case of lowering a light load of 4 tons placed at the end of the jib, and suppose the tail of the jib to be exactly in line with the cylinders A, B, C, as in Fig. 11, Plate 89, and that A was the cylinder open to the accumulator; then the weight hanging on the end of the jib was pulling the jib down on the one side, and the cylinder open to the accumulator was forcing it up on the opposite side. He thought that tended to throw a good deal of friction on the centre ram or guide; and the effect would not be much less in any other position, while one ram was out of use. With regard to the weights, the specified pressure on the rams was 400 lbs. per sq. in., not 600 lbs. as assumed by Mr. Walker; so that the area had to be made large on that account. The weight of the part of the crane that was lifted was about 7 tons 10 cwt., not 12 tons.

With respect to Mr. Holley's system of removing the converter for lining, at the time when the paper was written, before the works were started, the basic linings were found to be giving much trouble;

and he therefore thought it was desirable to mention a system by which the converters might be quickly changed.

Mr. Walker seemed to recommend great economy in the engine, but not to think the same was necessary in the boiler. The Turner boilers referred to had however worked with marine engines at about $1\frac{1}{3}$ lb. of coal per I.H.P. per hour.* On the other hand, people did not always get at the truth about consumption, and many boilers that were supposed to be running at $2\frac{1}{2}$ lbs. were really running at $3\frac{1}{2}$ or 4 lbs. per I.H.P. per hour; so that a saving of 1 lb., as suggested in the paper, was by no means impossible. He could not understand the Lancashire boiler developing 1 H.P. for 14 sq. ft. of grate surface, when a boiler of the most economical kind, such as Turner's, required 17. The ordinary Turner boiler had been made for a marine funnel, which would be about 40 ft. high; but the one erected at Barrow was connected to a chimney stack 250 ft. high. He thought also that a boiler of that type got more value out of the coal than the ordinary type of Lancashire boiler. Lately the Barrow Shipbuilding Company had dispensed with Lancashire boilers, and were using the ordinary type of marine boilers, and they had thus effected a saving of 20 per cent. in coal. The Midland Company at Derby had adopted locomotive boilers—another type of tubular boiler—which they found more economical in the long run than the ordinary type of stationary boiler. With regard to Mr. Cochrane's remarks, it was singular that the Turner boiler referred to was ordered to replace one of the water-tube boilers—not Root's, but a similar one; and the particular form of the Turner boiler was selected because it fitted into the place that the other one had occupied.

Perhaps at Barrow they were rather apt to overlook the objection that had been raised as to quality of water, because they had there some of the best water in England, and were never troubled with any sediment or scaling.

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* Mr. Turner has since communicated to the Secretary the results of the performance of his boilers during the trial trip of the steamship *Armathwaite*. The trial lasted five hours; the coal was carefully measured, and the total quantity consumed was 38 cwts.; the mean indicated horse power was 630; hence the coal burnt per I.H.P. per hour was 1·35 lb.

Mr. Head had mentioned that the weekly output at the Erimus works was 700 tons of steel rails. The steel plant had been made for 1,000 tons, but the mills had been overpowered already by the output from the converters—thus confirming Mr. Bell's statement. The mills were originally put down for 70-lbs. iron rails, but were only fit for 40-lbs. steel rails. As to the temperature at which steel was rolled, he thought it was generally acknowledged that, if the steel was allowed to get cold, immense power was required to finish the rails. The power required seemed to increase about as the cube of the difference in temperature between the steel bloom and the finished rail: so that, although such rails might be better in the long run than those rolled at a higher temperature, they were a good deal more costly to make.

Mr. Bell asked leave to say that he had simply mentioned as a matter of fact that steel rails were rolled at a lower temperature than iron, and so required much more power. At the same time it should be remembered that steel rails were rolled so quickly, that they developed a great amount of heat in the very process of rolling.

ON COMPRESSED-AIR ENGINES FOR TRAMWAYS.

By Mr. W. D. SCOTT-MONCRIEFF, of London.

The theoretical laws which apply to the use of Compressed Air as a motive power are now so well understood that any discussion of them in this place is unnecessary. Their application to practice however is often attended with considerable difficulty; and some account of the writer's experience in the matter, which has been large, may perhaps be interesting.

It seems desirable to state at the outset that compressed air should be adopted for Tramways in those cases, and in those cases only, *in which it is found to be the cheapest available power.* Although this remark appears to be a truism, and is equally applicable to water-power, steam-power, or any other form of energy, yet it is one that is continually overlooked in practice. One set of persons persistently look to the use of steam-power in cases where it is not even available, while others look to compressed air in cases where it is available but not economical. But taking this proposition as a starting-point, it becomes the duty of an engineer to study first of all the economy of the motive power actually in use, that is, in the case of the great majority of tramway lines, the economy of horse traction. Having satisfied himself that other kinds of motive power would be cheaper, if they could be applied, his next duty is to select those kinds for comparison which are at once economical and also available. The most familiar forms of force, such as wind or water power, are not available; and the force of steam would probably occur to the minds of most people as the next on the list. It is needless to refer to the great expenditure of money that has been going on for many years, in the endeavour to prove that steam-power is the most economical force available for the propulsion of tramcars. But even in 1873, when the writer first began seriously to turn his attention to the subject, he made

up his mind that steam was not available in crowded thoroughfares; and before long he became convinced that, even if it were available, it was not so economical as compressed air for this especial purpose.

The reasons which led to this opinion are as follows. Firstly, the fact that the generation of energy in the steam-engine takes place at high temperatures, and under conditions of excessive wear and tear, led him to believe that the depreciation upon a simple type of stationary boiler, together with the air-receivers in a self-moving car, would be much less than on a locomotive engine. This, he believes, has been fully borne out by the experience of those who have contracted for hauling by steam-power upon tramways. The maintenance and repair of a properly constructed air-receiver is amply covered by an allowance of 5 per cent. per annum. On the other hand 20 per cent. would be a somewhat sanguine allowance for renewals and repair upon the boiler of a small tramway locomotive; probably the experience of members of this Institution will not place the estimate at a lower figure. Secondly, the strong point of the steam locomotive is that it converts the heat of the furnace directly into the work necessary for the propulsion of vehicles. But the writer is by no means sure that even in this respect the economy is greater than with air. His reasons for this doubt are twofold. First, the cost per ton of fuel available for use in a large stationary boiler may be taken roughly at half that of the fuel which it is necessary to use in a boiler passing through crowded thoroughfares. Supposing then that the proportion of the power from the stationary boiler available for actually propelling the vehicle is only half that from the locomotive, if the cost of the fuel is also half, the coal account of the rival systems will balance. But secondly, if the character of the two classes of engines be considered, it will then be found that the balance is in favour of compressed air. If a small steam locomotive burns per I.H.P. per hour 5 lbs. of fuel at 20*s.* per ton, and the stationary engine burns only 2½ lbs. at 10*s.* per ton, then not only is the loss upon the use of compressed air compensated, but a large margin is secured in its favour. With regard to the fairness of these figures, the writer is not able to say whether 5 lbs. of coal per I.H.P. per hour, costing on the average 20*s.* per ton, is a fair estimate or not for a

steam tramway engine. From his own experience however he is able to state that 50 per cent. of the work done by the stationary compressing engine ought to be available for work in a compressed-air engine. Again, a high-class stationary engine on a large scale can undoubtedly be worked at an expenditure of $2\frac{1}{2}$ lbs. of coal per I.H.P. per hour; and 10*s*. per ton is not too low an average to take, at least at present, as the price of furnace coal in ordinary situations where tramways are used.

An engineer using steam as a tractive force upon tramways is troubled with three standing difficulties;—first, the products of combustion; secondly, the escape of visible vapour; and lastly, the alternative difficulty, either of a separate engine occupying space in the streets, or of a combined engine and car, causing annoyance to the passengers from smell and dirt. With regard to the first difficulty, even if the products of combustion may be disguised or ameliorated, it is impossible to ignore the fact of their existence. So long as there is a chimney at all, there is sure to be something coming out of it. With regard to the next difficulty, or the escape of visible vapour, it may be admitted that more complete success has attended the efforts that have been made to get rid of it than at first there was reason to expect. But however successful these may be, escaping steam must still remain, at least in the form of a complication requiring some separate device to suppress it. If condensation is adopted, extra weight becomes necessary in the form of water; and this is a serious objection in itself. Other systems, such as rendering the aqueous vapour invisible by passing it through the furnace, cannot be looked upon as proof against such a contingency as careless stoking. In fact the vapour, which in the case of ordinary locomotives is not objectionable, is a real source of trouble when it comes to be dealt with in streets. The last difficulty with regard to steam may be spoken of as a dilemma. There is great objection on the one hand to having the available room in a crowded thoroughfare occupied by a separate locomotive, in addition to the space taken up by an ordinary street tramcar, which is of an exceptional length in itself as compared with other kinds of carriages. This may be not unfairly likened to the case of a vessel being towed by another vessel in a

crowded channel. But besides the objection on the score of occupying excessive space, there is the additional difficulty of shunting at the ends of the journey. In many situations such an operation would become an intolerable obstruction to the ordinary traffic of the street. At such a terminus as the one in Hampstead Road, London, abutting on the Euston Road, the shunting of tramway engines would probably be altogether impracticable. With regard to the alternative of having a steam-engine and car self-contained, the writer is convinced that such an arrangement will never be popular. For these reasons he concludes that steam is neither the most economical nor the most available form of power for propulsion on tramways.

The writer will now go on to describe the apparatus which he has employed for working with compressed air, and give the reasons which led him to adopt it. The objections to a separate locomotive, which have just been spoken of, led him to fix upon a self-moving car, as shown in Figs. 1 to 3, Plates 90 and 91; the more so as no objection on the score either of heat or of smell could be urged against such an arrangement, where the motive power, after having done its work, escaped to the atmosphere in its original purity. Having determined upon incorporating with the vehicle itself the engines and the reservoirs containing the compressed air, the method of doing so was forced upon him by the conditions with which he had to comply. The convenience of the passengers must not be interfered with by the apparatus necessary for the propulsion of the car; and the only space available, consistently with this requirement, is beneath the level of the floor. The next point for consideration was the arrangement of the wheels. In the case of an ordinary horse-car, the difficulties attending the passage of sharp curves are got over by simply adopting two pairs of wheels with a small wheel-base. Although this system is by no means perfect, on account of the great amount of friction which is inseparable from its use, it has the merit of simplicity; and this, in spite of its theoretical disadvantages, has led to its almost universal adoption in preference to more complicated appliances. The writer accordingly determined upon dispensing with the use of swivels or bogies, and found that the best position of the engines, under such an arrangement, was in immediate proximity

to the wheels, in the centre of the vehicle. It then occurred to him that the more complicated part of the apparatus, consisting of the moving parts, might be arranged on a separate framing. The advantage of this plan is obvious in the event of the engines requiring to be repaired, because this can be done by removing them bodily and substituting a duplicate set of apparatus, without losing the use of the valuable plant represented by the car-body and the air-receivers. Two sets of framing accordingly became an essential feature of the plan; the one embracing the engines and wheels in the centre of the car, and the other overhanging it at each end, and carrying the air-receivers and the car-body. The wheel-base adopted was the mean of those which have been used by one or two of the leading Tramway Companies, namely 5 ft.; and allowing sufficient clearance for the wheels, the length of the central engine-framing came to be about 8 ft. In this way the spaces available for the reservoirs of compressed air arranged themselves at each end beneath the floor; and it was only left to consider how these could be constructed so as to combine the maximum of strength, lightness, and capacity.

The last of these conditions being of great importance, the writer was anxious if possible to take advantage of all the space by making the reservoirs rectangular in form. He found however that the staying of such large flat surfaces entailed an amount of weight which rendered the plan altogether impracticable. Cylindrical receivers being the only alternative, he found that the maximum capacity consistent with strength and lightness would be attained by filling up each of the spaces with three cylindrical receivers A, Figs. 1 to 3, Plates 90 and 91, each 2 ft. in diameter, and the full length of the overhanging space, or 8 ft. The construction of these air-cylinders was the next point to be considered. The plan first adopted is shown in Fig. 4, Plate 91. The cylinders were made from one plate, welded at the seam; and the ends were formed from circular plates, dished with the flanges facing outwards. This arrangement afforded an opportunity for riveting the dished flanges in a thorough manner. The stays had their nuts faced, along with the edges of the cylinders and dished plates, and, projecting through the end framing, were secured by an additional nut on the outside:

a mode of attachment which in practice was found to be thoroughly reliable. The great objection to this arrangement was the expensive work it entailed, as well as the additional weight required for staying the flat ends. For a long time the writer could find no means of supplying their place with hemispherical plates, so as to dispense with the necessity for staying altogether; but at last a process of welding by means of gas jets, used in Staffordshire, was tried with great success under the inspection of Mr. Hector MacColl. Although the working pressure was only about 22 atmospheres, the receiver was tested to 750 lbs. per sq. in. The name of "Dudley bottles" has been given to this form of receiver, in which the hemispherical ends are simply welded to the ends of the cylinder, Fig. 5, Plate 91, so as to form a solid surface throughout. The only apertures left are one hole in the centre of each end, about $\frac{3}{4}$ in. diameter. This suffices not only to afford the smith an opportunity of judging of the heat inside, after one end has been finished, but also as a means for intercommunication among the receivers by the attachment of suitable piping.

The general arrangement and details of the machinery, and its relation to the car itself, are sufficiently shown in Plates 90 to 93.

It is now desirable to explain the peculiar nature of the problem which has to be solved in dealing with the motive power supplied by a reservoir of compressed air. First, as regards the supply of energy, we have a reservoir of force that is continually decreasing in intensity and in amount. Secondly, we have to deal with an amount of resistance which may either remain uniform, as in the case of going along a level at a uniform speed; or may be slightly diminished or altogether disappear, as in going down a gentle or a steep incline; or may be greatly increased, as by the ascent of a steep gradient, or by the necessity of starting the vehicle from a state of rest.

First, suppose the resistance to be constant. Two methods of dealing with the varying intensity of the elastic force were already well known to engineers; one by first reducing the pressure before making use of it, the other by expanding it from its initial

pressure. By the first method it would be practicable always to lower the pressure of the air, before using it, down to the minimum required for propelling the vehicle when at the point of exhaustion near the end of the journey. If this plan were adopted, the dimensions of the engines could be adjusted to do the work, at least on a fairly level line, without any special expansion appliances. The disadvantage of this system is that it entails the loss of a great amount of energy. On referring to the diagram, Fig. 7, Plate 91, this becomes evident. If we start on our journey with a pressure reduced to 100 lbs. per sq. in., as against the 300 lbs. initial pressure, the loss of energy is represented at first by four times the area B C D E for every revolution of the wheels, in the case of a two-cylinder double-acting engine. This area will continually decrease with the decreasing pressure, but the gross loss is evidently so great as to render it most important that it should be avoided. Another disadvantage of this system is that, even when the receiver pressure has been reduced so low as to one-third of the original pressure, a great loss still arises, in the case of overcoming heavy resistances, by the discharge of the air at the end of the stroke at a pressure considerably above that of the atmosphere. This is needful in order to obtain a mean pressure sufficient to do the work under these circumstances; and the loss cannot be prevented by using larger cylinders, because then it is not possible to cut off early enough to suit the lighter resistances. It appears therefore that compressed air continually sinking from a high to a low pressure in the reservoir cannot be dealt with by the expedient of simply reducing the pressure before using it, without a great loss of power.*

It occurred to the writer however that an apparatus might be arranged, which would adjust the expansion valves so as to cut the air off at a different point for each decrease of the initial pressure in the reservoirs. It is true that at that time the experience of

* In the diagram isothermal lines have been chosen to illustrate the meaning, on account of their simplicity. If adiabatic curves had been taken, allowing for the thermal equivalent of the work done in the cylinders, the same remarks would have applied to them at a higher point upon the scale of pressures.

engineers had been going to show that early expansion was impracticable, in the case of compressed air admitted to the cylinders at the ordinary temperature of the atmosphere, on account of the excessive cold produced at the point of discharge, which, in an average aqueous condition of the air, led to the formation of ice. We have a familiar instance of the mode in which an elastic fluid at a high temperature is capable of converting its heat into work, by communicating momentum to its own particles, in the case of high-pressure steam escaping from an orifice. The absorption of heat, which takes place in this sudden transformation of one kind of energy into another, makes it possible to place the hand in contact with the steam at the point of escape. It seemed probable therefore that engineers had not expanded the air far enough; and that if they only did so in such a manner that the escape took place at the pressure of the atmosphere, the loss of heat would be only the mechanical equivalent of the work done in the cylinders, without the additional loss of temperature, at the end of the stroke, which occurs when a residual pressure is left to communicate momentum to the atoms composing the elastic medium. The writer found this to be the case by experiment; and thus showed that troubles from the formation of ice were only likely to arise when the air escaped from the cylinders above the pressure of the atmosphere.

Fig. 8, Plate 91, shows the automatic apparatus devised for the purpose of expansion. Here A A are the cylinders, in which the air is expanded and does the work of propelling the vehicle. In the chamber B is confined a quantity of air at a pressure corresponding to the pressure in the receivers. C is a chamber, at right angles to the air chamber B, filled with a suitable liquid so as to provide a hydraulic instead of a pneumatic connection with the piston D, which moves backwards or forwards as the pressure upon either side of it is increased or diminished. The piston-rod E is attached to a toothed rack F, acting upon a pinion G, which revolves in a piece with the wheel H; and this in its turn gives a rotary motion to the pinions J J keyed to the valve spindles. These spindles, being turned to the right or left, give motion to cut-off valves placed upon the backs of the main valves, by altering their relative positions through the agency

of right- and left-hand screws. In this way the movements of the piston D are conveyed directly to the valves, so as to vary the period of cut-off in accordance with the position of the toothed rack.

We must now return to the diagram, Fig. 7, exhibiting the dynamical values of different degrees of expansion at different pressures, in order to understand how the mechanism described will effect the object aimed at. Still taking the isothermal curves for the purposes of comparison and explanation, it will be found that if we require a mean pressure of 60 lbs., this will be given by the outer black line B H, provided we commence with the initial pressure of 300 lbs. and finish with the pressure of the atmosphere at the end of the stroke. But after the reservoir pressure has fallen to 100 lbs., this mean pressure can only be obtained by cutting off at a point much further out on the line of volumes; in fact as nearly as may be at one-fourth instead of one-twentieth of the stroke. Omitting for the moment the mode of meeting the difficulty that the final pressure in this case is above that of the atmosphere, let us turn to the apparatus, Fig. 8, and see what it has done in the way of adjusting the valves in the desired manner. It must be understood that the pressure from the receivers, during the process of pumping the compressed air into them, is admitted to the forward end of the piston D in the space Q, and therefore as the pressure rises it forces back the piston, until the motion is arrested by the elasticity of the confined air in the chamber B. Suppose now that the maximum pressure in the receiver has been reached, and that the piston D has been moved back so that the valves are adjusted to their earliest points of cut-off; and suppose also that the car has been detached from the pumps and has started on its journey: then, as the pressure in the receivers begins to diminish, the piston D will be moved forward by the higher pressure of the confined air in the chamber B, and the point of cut-off will be rendered correspondingly later.

Again turning our attention to the diagram of the isothermal curves, Fig. 7, Plate 91, we must see if the expansion of the column of confined air behind the piston D will produce the

desired rates of expansion necessary to maintain a constant mean pressure in the working cylinders. In the first place, by Boyle's law, when the pressure has been reduced in the receivers by one-half, say from 300 lbs. to 150 lbs. per sq. in., then, the pressure of the air confined in the chamber B being correspondingly diminished, its volume will have exactly doubled. The toothed rack, if its travel corresponded to the change of volume, would then have moved through half its stroke; and would thus have moved the valves half way towards their latest point of cut-off. In order to simplify the explanation, we will suppose that this half-stroke of the rack will also cut off the air at half-stroke. Then we find that the mechanism will be cutting off the air at half stroke, when the initial pressure in the receivers is 150 lbs. What is wanted however, as we have already assumed, is a mean pressure of 60 lbs. per sq. in.; and, in order to attain this, the point of cut-off must not be at the point of half-stroke P, Fig. 7, but at the point N, very nearly one-eighth of the stroke. This difficulty is overcome by making the capacity of the chamber C, containing the liquid, four times that of the air-chamber B. If this is done, it is evident that for every inch through which the column of confined air expands, in correspondence with the decreasing pressure in the reservoirs, the piston D will move through one-fourth of an inch. When therefore the column of air has expanded to double its volume, the piston, with the toothed rack and expansion valves, will have moved only one-fourth of that distance, or one-eighth of its entire stroke. This then will bring the cut-off not to the point P, Fig. 7, but to the point N, which represents the approximate ratio of expansion necessary to give the required mean pressure of 60 lbs.

A variable cut-off, as may be required, is easily obtained by means of a two-way valve, attached to the pipe that communicates between the receivers and the chamber Q in front of the piston D. If this valve is turned so that the communication is closed to the receivers and opened to the atmosphere, the pressure in this chamber is instantly reduced, and the elasticity of the confined air in the chamber B immediately thrusts the piston D forward, so as to set the valves to a later point of cut-off. This forward movement of the piston is

allowed to continue until the desired rate of speed has been attained; the two-way valve being used to the same effect as an ordinary stop-valve until the end of the journey. Here then we have obtained an apparatus which acts correctly in an automatic manner throughout the distance travelled by the car, in ordinary cases, and which is capable of being readily adjusted at any time of the journey, to suit special cases.

On turning to our diagram of the dynamical areas, Fig. 7, Plate 91, it will be found that many difficulties have still to be overcome. In the first place the ratio of the cubic contents of the two chambers B and C, when arranged as 1 to 4, is only right for the isothermal lines, which we have already made use of for the purpose of explanation, besides being only correct for ordinary conditions of the journey. What next has to be done is to adjust the two areas so that the points of cut-off will give the required mean pressure for a corresponding series of adiabatic curves, in which allowance is made for the loss of power in the air when it is doing work by expanding in the cylinders. Now if we suppose the amount of work to be constant—which it will be so long as it is employed to overcome a constant resistance, as in the case of a uniform load travelling at a uniform velocity along a level—then the dynamical area which we must add to the isothermal area, in order to allow for this work, will be a constant quantity; and we shall be able to supply the deficiency by an adjustment of the two areas B and C to some ratio greater than the ratio of 1 to 4; say 1 to 3, or 1 to 2. This variation in the ratio between the cubic contents of the chamber B and the chamber C can always be adjusted by reducing or increasing the quantity of the liquid.

On once more examining the isothermal lines, it will appear that there are yet further difficulties to be overcome. Hitherto we have dealt with a supposed *maximum* mean pressure of 60 lbs., used to overcome a supposed *maximum* resistance. Now if we look at the outer line B H, Fig. 7, which starts from the line of maximum initial pressure, we find that it supplies the conditions of a mean

pressure of 60 lbs., terminating at the pressure of the atmosphere at the end of the stroke. Let us now turn, not to the maximum mean pressure required to overcome the maximum resistance, but to an *average* mean pressure required to overcome an *average* resistance, say 30 lbs. instead of 60 lbs. We then discover that the point of cut-off at the maximum initial pressure of 300 lbs. requires to be moved from the point B to A; and the result of this earlier expansion is to bring the isothermal line across the atmospheric line at the point X, somewhat beyond the centre of the line of volumes, or in other words beyond the half-stroke of the engine. In this way a dynamical loss will occur, on account of the back pressure of the atmosphere, this loss being represented on the diagram, for each stroke, by the area H I X. It is evident that one way of getting over this difficulty would be, so to reduce one or more of the factors that go to make up the total capacity of the engine, as that a different line of mean pressures, ending just at the atmospheric line, would be required to overcome the supposed mean resistance. For instance, let us suppose that in order to bring out this result we have recourse to the outer line B H, giving a mean pressure of 60 lbs., and reaching the atmospheric pressure at the end of the stroke; while at the same time we do not wish to use more work than is represented by 30 lbs. mean pressure in a two-cylinder double-acting engine. It is clear that this object may be attained either by using only one cylinder instead of two, or by making the two cylinders, for the time being, single instead of double-acting.

So much for the earlier and higher initial pressures: let us now look at what happens when we come to consider such a reduced initial pressure as 100 lbs. What we now require is to bring the point of cut-off further in on the line of volumes than the point F, which is the point of cut-off corresponding with a mean pressure of 60 lbs., and in this way to terminate the isothermal line at the point H on the atmospheric line, instead of at G; so as to save the residual pressure at the end of the stroke represented by the height G H. To do this we must reduce the mean pressure below the supposed maximum of 60 lbs.; and in order to make up for this reduction we must increase the capacity of the engines beyond the capacity we started

with when the initial pressure was 300 lbs. In short, if we take the capacity of the engines as unity when the mean pressure of 60 lbs. is required in order to overcome an incline, we must at first reduce their capacity to say 0·6, in order to obtain the normal amount of work which is required on a level road, and at the same time terminate the stroke at the pressure of the atmosphere; and on the other hand, when the initial pressure is reduced to 100 lbs., we must have an earlier cut-off if we are to finish at atmospheric pressure, and must increase the capacity of the engines above unity in order to make up for it.

For many months the writer worked at the solution of this difficult problem; *i.e.* how to vary the capacity of the engines, so as to secure the discharge of the air at the atmospheric pressure, for every variation in the initial pressure and every alteration of the work required. An ordinary double-acting two-cylinder engine so far supplied the elements of increasing and decreasing the total cylinder capacity, that it would be possible to use first a single cylinder single-acting, then a single cylinder double-acting then two cylinders one double-acting, and lastly two cylinders both double-acting. This course however had many inherent defects, besides the complication entailed by the necessary apparatus. Finally the author struck out the true solution of the problem. A few words will suffice to explain it. Supposing we take the initial pressure of 100 lbs. as the mean residual pressure in the receivers, which we think to be desirable at the end of the journey. Suppose also we make the capacity of the engines so large that the mean pressure of 60 lbs. can be reduced, so as to bring the residual pressure down to that of the atmosphere at the end of the stroke, and yet obtain a dynamical area, even with 100 lbs. pressure, sufficient to overcome the maximum resistance. Suppose further we keep this same engine capacity for every degree of expansion and for every variation of initial pressure and work. Then it follows that the whole of the curves enclosing our dynamical areas will fall below the atmospheric line before the end of the stroke. Take for instance the standard curve represented by the outer strong line B H, Fig. 7, Plate 91. As the capacity of the engine has been

increased to meet the necessities of the reduced initial pressure of 100 lbs., it is clear the maximum mean pressure of 60 lbs. must be reduced by means of an earlier cut-off, and thus the curve must fall below the atmospheric line, if its dynamical effect is to remain the same in the larger engine as in the smaller one. Here then we have the phenomenon to deal with of all the adiabatic lines falling below the atmospheric line at the end of the stroke, except a few that touch it, at the lowest initial pressures towards the end of the journey. Now these various lines represent variations in what may be called the "dynamical duration of the stroke," and that in a perfectly automatic manner. But this dynamical duration of the stroke, when varied, has just as much effect upon the total capacity of the engine, as if the area of the cylinder were altered. Here then was the automatic variation in the capacity of the engine which was required.

The only thing was to devise a means by which this variation should be obtained, without the back pressure of the atmosphere acting through the remainder of the stroke. A simple suction or inlet valve, Fig. 11, Plate 93, supplied the want, by admitting the outer air to the cylinder whenever the pressure fell below the atmospheric pressure. By its application an absolutely automatic variation in the capacity of the engine is obtained, by the variation of the dynamical duration of the stroke, without any loss from the back pressure of the atmosphere. Very important consequences follow from its adoption. Any desired position of the valves can be given, in order to overcome any resistance, at any speed, with the certainty that the power is being obtained without loss. Now, since the speed is what decides the necessary degree of expansion, however the resistance may vary, it follows that the driver, being the best judge of the speed, may use his valve-gear just as he would a stop-valve ; and the automatic arrangement shown in Fig. 8, unless under the peculiar circumstances of a constant resistance, becomes unnecessary.

Although the problem was in this manner successfully solved, practical difficulties still remained. The necessity for continually starting the car from a state of rest is a source of trouble and loss of

power, when the valves are placed at an early point of cut-off, and when the position of the cranks happens not to admit of any air being admitted to the cylinders. In order to avoid the necessity for completely altering the position of the expansion valves, the writer adopted the device, shown in Fig. 12, Plate 93, of admitting a small jet of air directly from the receivers through the main valve face, so as to enter the cylinders under the control of the main valve alone, and unaffected by the expansion valve. In this way the vehicle can be started almost as quickly as if the expansion valves did not exist.

One point of importance remains to be spoken of, namely the heating of the air before it is made use of in the cylinders. The dynamical advantage of this operation is so evident that it has already been adopted by other inventors. The writer has hitherto refrained from adopting it, because he considers that any economy that may arise from doing so really affects only the fuel account of the engine. Against this saving is to be placed the inconvenience to the public, arising from the necessity of a separate apparatus for producing the heat. Now the expense of the fuel for driving the writer's car is only about a halfpenny per mile, when used on a large scale, and when furnace coals are to be obtained at 10*s.* per ton. The present car, as made by the writer's licensees, Messrs. Neilson & Co., Hyde Park Locomotive Works, Glasgow, travels 7 miles with one charge of air at the moderate pressure of 26 atmospheres, and this with a load of 40 passengers and including about 25 stoppages and reversings of the engines. It is clear that the insignificant saving due to heating the air is not worth having, at least on such a route.

In conclusion, it may be observed that the subject of compressed air as a motive power is a very much wider one than can be dealt with in the limits of a single paper. The case of tramways is by no means that which offers the fewest obstacles to its application. In long tunnels, for instance, the requirements as to noiselessness &c. would not be needed. At the same time the present paper has shown how a silent exhaust may be obtained, and how it at once secures an

economical use of the air, and evades the difficulty of the formation of ice. Wider questions, such as the use of compressed air for conveying power to a distance, cannot now be touched on. The writer wishes to conclude by expressing his opinion that the action of the Board of Trade, on the question of mechanical traction upon tramways, has been most judicious; and that their present code of rules (if a little latitude be allowed in regard to such matters as the self-acting governor and speed indicator) is very fair and reasonable.

Discussion on Air Tramway Engines.

Mr. Scott-Moncrieff said he would endeavour more fully to explain the ultimate result obtained by the use of the inlet air valve shown in Fig. 11, Plate 93. The way in which the matter stood from a practical point of view, as regarded both the traction of vehicles and also the use of such an elastic fluid as compressed air in a stationary reciprocating engine, was simply this: that, to avoid the escape of the air above the pressure of the atmosphere at the end of

the stroke (which had the double disadvantage of producing excessive cold and a loss of power), the size of the cylinders must be increased. Then the cut-off could be made earlier, so bringing the exhaust down to the atmospheric pressure at the end of the stroke, and reducing the mean pressure as compared with the smaller engine, but maintaining the power by reason of the additional capacity. But the difference between the problem of a stationary air-engine and that of a tramway locomotive was that in the former case there was an approximately constant reservoir pressure to draw from, in order to supply a required mean cylinder pressure; while in the latter case there was a constantly diminishing reservoir pressure; and the devices which had been described in the paper had therefore to be adopted in order to obtain the required result. In such an apparatus as a self-moving car it was necessary to start with a maximum size of cylinder, having a capacity sufficient to overcome a maximum resistance, and yet to cut off so early as to obtain an exhaust terminating on the atmospheric line. The question then came to be, what was to be done with the lighter resistances? The true method, as the paper explained, was simply to allow those reduced mean cylinder pressures to adjust themselves: the dynamical capacity of the engine constantly varying by the fact of the stroke, or rather the dynamical duration of the stroke, being reduced whenever the cut-off was made earlier; and all loss from back pressure being prevented by admitting the atmospheric air the moment the exhaust touched the atmospheric line.

Mr. George Allan asked what was the weight of the combined engine and car, and also what was the steepest incline it could travel up.

Mr. Henry Hughes desired, as an old opponent of Mr. Moncrieff, to say how much he admired the courage with which he had stuck to his subject during so many years. Mr. Moncrieff, he believed, was the first man to think of working a tramway by compressed air. Many others had followed in his wake; and only last week he had seen the name of Mr. Hardie mentioned, who was now working a tramway in

America by compressed air, and who, he believed, was a pupil of Mr. Scott-Moncrieff. He was certain that no man had pursued that subject with more zeal, or had obtained better results.

It was stated in the paper that that which was found to be the cheapest available power was the best for tramways. He supposed that the cheapest meant that which, of those best suited for the purpose, cost least for fuel and least for repairs. They would all agree with that; but he could not agree with the author that the working of a locomotive by steam would be less economical than the working of a locomotive by compressed air. It was stated that the fuel would cost about half the money per ton, and also that the efficiency was about one half, in the compressed-air engine as compared with the steam engine; so that the two balanced. But then it was added that the fuel used and the heat produced in a steam locomotive involved much more waste than in the compressed-air engine, and therefore there remained an advantage on the side of the latter. With this he could not agree; because it must not be forgotten that in a steam tramway engine no blast was used, that all the fuel was used in the best way possible, and that nearly the whole of the heat was taken up just as it would be taken up in the very best boilers to be found. With regard to the three standing difficulties mentioned on p. 651, he could not see that there was much to complain of in the products of combustion from a well-designed steam tramway locomotive. The smoke from the chimney was very small; and if mechanical engineers could not get rid of the gases from the fire, when no blast was passing through the chimney, the more shame for them. He had run many hundreds of thousands of miles by steam on tramways, and had never had a single action brought by persons who complained that they had been damaged by the gases; and he did not believe that the proprietors of the tramways had lost a penny by passengers refusing to ride on them for that reason. The escape of visible vapour, as Mr. Moncrieff admitted, was entirely done away with by condensation; but he added that the weight of the water carried was a difficulty. He himself had always found, on the contrary, that the weight of water carried was of very great advantage. Anyone who had to take a tramway engine up a gradient of 1 in 12

(as he had himself lately done with Mr. Chamberlain in Birmingham), and that with the rails rather greasy, would find that, instead of wanting less water in the tank, he would want more: at least he would be only too glad to have a tank full of water to weight the engine. As to occupying space in the streets, no doubt the engines did occupy space; and at a place like the corner of Euston Road, cited in the paper, he doubted whether even a compressed-air engine would be suitable; but there were hundreds of other places where tramway engines could be usefully located. There was very little difficulty in the shunting of a locomotive and separating it from the car in the public street. It was not necessary to run the engine forward, and bring it round to the other end of the car. The proper plan was to take the engine off the car, to run it on to an adjoining siding, and there couple it to another car which was waiting filled with passengers. The operation occupied very little time and space. It was desirable however that all steam tramways should have double lines, in order to avoid the use of facing points, which on single lines occurred at very short intervals, and were highly dangerous.

The strength of a chain was the strength of its weakest part; and the weak part of compressed air was that you could not increase the power as you wanted it; you could only use the power that the compressed air in the receivers would give you. He knew, from practical experience with many tramways worked by steam, that an enormous amount of force was sometimes required. It sometimes happened that when the driver came in the morning he found say six inches of snow on the ground. He then told the fireman to fill the fire-box full of fuel, to put the blast on, and get up plenty of steam, say 140 lbs. pressure. He then started out with a good fire, and ran the engine over the road, at first without any car, pressing the snow down; after which all the cars would go over it very well. He would undertake to say that with a compressed-air engine it would take twenty times the air contained in the receivers to do the same work. Again, a steam engine, or a compressed-air engine, would often go wrong upon the road, and it could not be left there; it must be got out of the way. In Paris, for instance, he had had a steam brake stuck fast on the engine wheels more than once, so that it would not

come off. What did they do under such circumstances? The next engine coming up would get up steam pretty high, and push the first one on, although the wheels were skidded, and thus it did not lose a single journey. Those were circumstances in which an enormous amount of force was required, and that force must be at hand; but it was not at hand in the case of a compressed-air engine.

What was required for tramways in all cases was a strong engine and a strong road. The great difficulty in regard to the use of steam or air on tramways, in times past, had been that the roads had not been sufficiently good for the engines. In the case of a tramway worked by himself in Paris he was certain from what he saw that in the end the road would knock the engine to pieces. In consequence, having a contract at Lille, he had designed an engine with large cylinders and wheels, so that the friction was reduced, and the speed of the moving parts was slow. These were so strong that he felt quite certain the tramway would have to give way, and not the engine. The engine jumped off the tramway sometimes, but they managed to jump it on again. Once it went down a railway embankment; but it was drawn up again, and was not hurt. The tramway did give way, and the consequence was that the authorities put down a new tramway; and not only so, but they agreed to purchase the locomotives to work it.

There was now another competitor in the field, in the shape of electricity. Whether it would succeed or not he could not say; but he mentioned the matter because he had lately seen it stated (see "The Engineer," 7 Oct. 1881, p. 259) that, whereas steam cost 7*d.* per mile, electricity would only cost one penny. Now, on a tramway the highest rate of speed was ordinarily 6 miles per hour, and the men on the lines with which he was connected were paid 7*d.* per hour for driving the engines. Consequently the figure mentioned for electricity, namely 6*d.* for the journey of 6 miles, would barely pay the wages of the man. Probably an electric engine might be able to work without a driver; at all events the driver must work without the engine, or the engine without the driver, because the penny per mile would be wholly absorbed by the man himself.

It did seem sad that tramway companies would not adopt some kind of machine; for it was really pitiful to see, as he had sometimes

seen, three or four horses with their knees bent, their tails out, their backs strained, and apparently in absolute torture, while dragging the heavy vehicles along. With regard to the question of space, three or four horses occupied far more space than a locomotive would. Something certainly ought to be done to meet the case.

The President asked if Mr. Hughes could give any further particulars with regard to the engines working on the Govan Road, Glasgow.

Mr. Hughes said they had worked very satisfactorily for three or four years, but since that time another firm had taken the contract. The public were pleased with them, and the tramway company were anxious to make a fresh contract, and at a higher price; so that altogether the undertaking was a success.*

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* Mr. Hughes has since supplied the following particulars of cost of working on this tramway :—

No. of miles per day for each engine, 70.
Length of Tramway, 2 miles.
Hours of work, 7 o'clock a.m. to 11 o'clock p.m.

	Cost per mile run.	*Pence.*
Coke	10 lbs.	1·070
Water (including washing)	50 gallons	0·250
Oil	0·06 pint	0·270
Lighting Oil	0·015 „	0·033
Waste		0·025
Material, Repairs &c.		0·500
Labour		3·300
10 per cent. depreciation		0·835
Cost of Cars and Engines		6·280
Deduct cost of repair to Cars		0·200
Cost of Engines per mile		6·080*d.*

It should be noted that the tramway was in bad order, but on the other hand the gradients were not heavy. The mileage is small compared with that on some other tramways. An engine often took two cars, and sometimes three, so that the earnings of the company were much greater than with horses. Each car would require two horses, and the contract for horsing was at 7*d.* per mile.

Mr. Daniel Adamson said the question of the vessels to be used for containing compressed air had been well illustrated in the paper, both as to the first principles and the details of their construction: indeed he had been more favourably impressed by the paper, from the thoroughness and fairness of its descriptions, than by almost any paper he had ever heard. The author limited the pressure however to 300 lbs. per sq. in.; and no doubt he had done so from the difficulties of getting, first a vessel to contain a higher pressure, and secondly an apparatus to compress air to that higher pressure. There need be no difficulty however upon the first point. Fig. 6, Plate 91, showed a vessel made of mild steel, 3 ft. in diameter and 9 ft. long, which had been tested to a pressure of 1500 lbs. per sq. in., and was in daily work at 1000 lbs. per sq. in. No doubt the difficulty of using such a pressure with Mr. Moncrieff's engine would arise from its being a direct-acting single-expansion engine. If the cut-off was very variable, the work could not be accomplished in one cylinder without an enormous difference in the force at different times; but by the addition of other cylinders, giving a multiple action, the troubles with the expansion valve were reduced to one-half or one-third, as the case might be; and not only so, but a much higher pressure could be used with the same strain upon the crank-shaft. In the case before them, Fig. 7, Plate 91, the full pressure of 300 lbs. that must be used at starting brought a corresponding initial force direct upon the crank-pin; and that pressure afterwards diminished until it fell to 100 lbs. But if the high pressure acted only in a small cylinder, with a piston of one-sixth the area of the other, and working with compound action, there would then be only one-sixth the force coming as a direct strain upon the crank-pin at the beginning of the stroke.

With regard to working economically at a higher pressure than 300 lbs. per sq. in., he might say that the vessel shown in Fig. 6, Plate 91, had been made about two years ago. It was now in use in London for Colonel Beaumont, and was working daily at 1000 lbs. per sq. in. The compressing engines were compound, with four air-compressing cylinders, beginning at 12 in. diameter and ending, he believed, at $2\frac{1}{2}$ in. diameter. They gradually passed the compressed air forward from cylinder to cylinder, abstracting the heat

simultaneously with the compression, and forcing the pressure up to 1000 lbs. without any difficulty. Beyond that point very carefully made joints and apparatus would be necessary to retain the air. In his own case he had for three or four days been unable to get the pressure up to 1000 lbs. or 1200 lbs., simply from leakage in the joints of the last cylinder, and not only in the joints but in the joint brasses, where the air could be felt passing through. These were good brass castings, having a flange of 10 in. diameter, with only a 1-in. hole through, so that the air was actually passing through the solid brass for a distance of $4\frac{1}{2}$ in. That leakage was got over by altering the mixture of the metal, so as to adapt it to those conditions; and that was all the trouble he had to contend with. The vessel was 1 in. thick, and the tension due to the working pressure was exactly 8 tons per sq. in. of section. The test pressure was 1500 lbs., or 500 lbs. per sq. in. in excess of the working pressure. According to some recent investigations, the vessel under such a test pressure, equal to 12 tons tension per sq. in., would not take a permanent set or get out of shape. He had passed flat steel wire round the vessel, and marked it with a straight line across the two laps: then, on putting on the maximum pressure of 1500 lbs., there was not an atom of extension shown by the straight line being broken, and no permanent set took place, although the tension was 12 tons per sq. in. on the section of the metal.

Some of the gentlemen present at the last meeting held in Manchester had seen at his works Colonel Beaumont's six-cylinder engine working with compressed air at 1000 lbs. pressure. He believed that engine had run on the Metropolitan Railway since then as a trial. The next engine constructed by Colonel Beaumont was designed to use the same pressure with only four cylinders—two sets of compound cylinders, with cranks at right angles; the expansion being divided more evenly between the cylinders, and the power being nearly the same. The subject had since been further considered by himself in conjunction with Colonel Beaumont, and it had ended in the construction at his works of a tramcar engine with only two cylinders, adopting the marine system of connecting the cylinders to cranks at right angles. The first cylinder was

$2\frac{3}{4}$ in. diameter, and the second 10 in. The variation in the cut-off was regulated by a snifting valve (as the atmospheric valve on the old atmospheric engine used to be called), which was used much in the same way as the inlet valve described in the paper; and the driver, in going along, could tell by the sucking in or discharge of air, and by the chatter of the valve, whether he had too much or too little expansion on his engine, and could regulate the cut-off accordingly. The opening of the cut-off valve was by the ordinary link motion, but with the addition of a variable cut-off, beginning at about one-twentieth of the stroke. By means of that small cylinder, cutting off at one-twentieth of the stroke, they were enabled to use a very high pressure without much or any wire-drawing; and to continue working with the diminishing pressure till it got down to 100 lbs., that being the minimum that such an engine would work at. There were some difficulties in the right-angled position of the cranks, such as must arise where there was a high expansion. Thus when a locomotive starting on a railway had to start on the back stroke, the driver generally had to reverse before he could go on. To get over that difficulty with the compound system of construction, he had had a by-pass valve placed between the two cylinders, admitting air to them direct from the reservoir. The driver could actuate this valve by his foot, so that in case of reversing and not being able to get the air into the first cylinder, he could send it direct into the second cylinder by making a slight admission through the foot-valve. Hence the complexity of six cylinders was now reduced to two.

He differed entirely from the author in saying that superheating compressed air was of little value. In a vessel similar to that shown in Fig. 6, Plate 91, standing with a pressure of 500 lbs. per sq. in. within it, he had merely turned a jet of steam under it with free passage over the top, and the rise of temperature in the vessel, due to the condensed steam on the surface, instantly drove up the gauge to 550 lbs. There was thus a direct gain of 50 lbs. pressure with a very small rise of temperature. Superheating with ordinary steam, at a pressure of say 100 lbs., was a comparatively insignificant matter. For, according to Dalton's law, the increase in volume or

pressure was proportional to the increase in temperature; and the pressure was doubled, the volume remaining constant, by the addition of 480° Fahr. of temperature. Now it was quite practicable to increase the temperature by half that amount, and so increase the pressure or bulk by 50 per cent. But if the original pressure was only 100 lbs., then there would be only the advantage of 50 lbs. increase of pressure. When however there was 1000 lbs. to start with, if then the temperature were raised by 240°, the increase of pressure obtained would be 500 lbs. per sq. in., or an increase of bulk of 50 per cent.; and certainly that was no trifle, it was not a thing to be thrown aside. In adapting that principle to the Beaumont engine, with cranks at right angles, he used a small boiler having say 60 lbs. pressure of steam, or 300° Fahr. of temperature, within it. By that means the air was superheated in the first cylinder, and could be heated say up to 250° Fahr., as a practical temperature. That gave the advantage of increased pressure or bulk in the first instance. The cylinder required to be jacketed to keep up the temperature as far as possible, under the abstraction of its heat by expansion. But further, having a second cylinder and placing an air reservoir between the two, with large heating surfaces and thin air spaces, they could raise the temperature a second time between the two cylinders. Thus, instead of having to deal with the low temperatures which had a tendency to produce icicles at the point of discharge, they could increase the bulk or pressure of the air a second time, at a small cost for fuel, exhaust it at say 100°, and regulate the operation with the greatest nicety. In short, superheating might be, and was, comparatively an insignificant factor when dealing with low pressures; but when dealing with highly compressed air, not having a high temperature like high-pressure steam, it was a different matter. With hot steam there was no chance of superheating to advantage, and all attempts had failed; but when using air at 60° Fahr., and raising its temperature by 240°, they had only a temperature to contend with equivalent to about 60 lbs. steam pressure in the boiler; and this was far too low to produce any injurious effect on the surfaces of the metals. The cylinders in the case he had described were made first of cast iron, and then bushed with a steel tube; so

that, having long pistons, and never using a temperature that would burn off the lubricants, they were in a very different position from that which they occupied when using high-pressure steam in connection with superheating.

He highly commended Mr. Moncrieff's attempt to get horse-flesh off the tramroads, and to do the work at very much less cost. The cost with his system was stated in the paper (p. 663) as one-halfpenny per mile for fuel. He believed that to be correct; but with compressed-air at 1000 lbs. pressure he thought the work would be done at a cost of not more than one-fourth to one-third of a penny per mile. He hoped that Manchester would not be backward in recognising, through its corporate body, these progressive applications of science. In olden times the Lancashire district was the first in England, and perhaps in the world, with regard to such matters; and he hoped that it would not lose its traditional character by allowing good inventions to be neglected.

M. Charles Bergeron said he had been asked by Col. Beaumont to state that an engine on his system was now working on the Stratford and Leytonstone branch of the North Metropolitan Tramways. The line was $2\frac{1}{4}$ miles long, with a rise of 82 feet in that distance; so that each trip, out and back, was $4\frac{1}{2}$ miles. The consumption of air, at 1000 lbs. pressure, was 10 cub. ft. per mile. It was found that the air could be compressed for an expenditure of 1 lb. of coal per cub. ft. of air at 1000 lbs., and no difficulty was found in dealing with the air at that pressure. Taking coal at 10*s.* per ton, this would mean an expense for fuel of about $\frac{1}{2}$*d.* per mile.

Mr. Joseph Tomlinson, Jun., said that with the first engine of Col. Beaumont, to which reference had been made, he had made two journeys over the Metropolitan Railway. She had six cylinders, one pair of $1\frac{1}{2}$ in., one of 3 in., and one of 7 in. diam., the three working on each side being connected. They started from the Edgware Road with 1000 lbs. of air, and the result of the journeys showed that the engine did 3 ton-miles for 1 cub. ft. of air, reckoned at 1000 lbs. pressure. Such an engine was utterly impracticable for a line

like the Metropolitan; but for purposes such as tramways he saw no reason why the plan should not be adopted; because the difficulty with regard to such large quantities as were required by the Metropolitan line did not then exist, and there was a large margin of cost to deal with as compared with horse-flesh. The paper stated that it cost $\frac{1}{2}d$. per mile for fuel to work a 7-ton tramcar; but the Metropolitan locomotives worked 150 tons over 1 mile for $1\frac{1}{2}d$. only. He had calculated that if Col. Beaumont's air engines were used for working the traffic of the Metropolitan line, they would require 26 Cornish or Lancashire boilers, 40 feet long, continually going day and night, to compress air enough to work the engines that went out of Aldgate Station. Again, with regard to the compressing machinery, of course everything would have to be in duplicate, or perhaps in triplicate; and the plant would altogether occupy some 5 acres—an amount of space that in the city would cost more than double the entire cost of the engine stock of the Metropolitan Railway. In dealing with such a railway therefore, the air engine was out of the field altogether.

The engine he had tried weighed ten tons; it had six pistons, and of course six connecting-rods, and ten valves. The first valve only moved 1–32nd inch. On a line like the Metropolitan, the driver would have continually to be altering the cut-off from one end of the journey to the other. Starting from Aldgate with 1000 lbs. pressure, he would go to Farringdon Street on the level; then up 1 in 500 to King's Cross; then up 1 in 100 to Portland Road.

The President asked if Mr. Tomlinson had taken a series of indicator figures under those various conditions.

Mr. Tomlinson said he did not think that any indicator ever made would suffice for the first cylinder. There was another objection to the proposed plan, for a complicated system like that of the Metropolitan Railway. A certain recuperative power was wanted from time to time. Thus, if in an ordinary locomotive a tube burst, they could get it plugged up in a few minutes, without losing much steam, and go on again; but there was no recuperative

power of that kind in the engine in question. He had had it pumped up to 1000 lbs., after a vast amount of labour, to send it to Chatham, where it would have more room to stand; but during the night one of the tubes burst, and in the morning the gauge was found to show 200 lbs., 800 lbs. of the pressure having leaked off during the night, and that from a very slight leak. When the tube burst in the first instance, they were afraid to go near to find out where the leak was; for it was a very serious matter to put the hand upon a small hole with air escaping at 1000 lbs. pressure. That difficulty, no doubt, was got over to a great extent by Mr. Adamson's reservoir, which he had seen proved to 1200 lbs. pressure.

The general difficulties of dealing with compressed air had been ably pointed out by Mr. Moncrieff; but he ought to go still further, if he intended to work out the problem, in the direction of Col. Beaumont's higher pressures. That seemed to be the only way of dealing with the matter economically. He should also follow the direction that Mr. Adamson had pointed out. It was absolutely indispensable that more heat should be employed. In the act of compressing air, heat was generated, which subsequently disappeared; that heat must be got back again in some shape or form; and the best plan was to get it back by heating the air at the inlet valve.

Mr. Benjamin Walker observed that Messrs. Kitson's steam tramway locomotive was working very successfully in Leeds, and the shunting caused less trouble in the street than changing horses from one end of the car to the other. He believed that such engines would be very popular and successful, and would do the work much better than horses.

Mr. J. G. Lynde said that Messrs. Kitson's engine was also working very satisfactorily on the tramway from Blackburn to Over Darwen.

Mr. Scott-Moncrieff, in reply, said he had been asked by Mr. Allan what was the weight of the car shown in the drawings, and what were the inclines overcome. He might mention that this

was not the first car he had made. The first car had wheels uncoupled, and it would overcome an incline of 1 in 20. That being so, the present car with its coupled wheels would be able to go up an incline of 1 in 10. The weight of the car was 7 tons 7 cwt., complete and ready for passengers.

He desired to thank Mr. Hughes for his kind and generous remarks towards himself, as an old rival, and he fully reciprocated them. With regard to the general question of steam versus compressed air, he thought he had sufficiently dealt with that in the paper. Mr. Hughes had spoken of the use of a heavy weight of water for condensing as not being a disadvantage in the case of ascending an incline; but it was almost unnecessary for him to point out that the advantage of additional weight in going up an incline could only exist in the case of a separate engine, where it was necessary to have additional weight in order to drag another vehicle behind it. In ascending an incline with a combined car, having both wheels coupled, the weight did not matter, except in so far as it might be said that the lighter it was the better. As to the exceptional circumstance of a fall of 6 inches of snow, it was not very extraordinary to have a still deeper fall than 6 inches; and he presumed if the snow was 12 or 15 inches deep, even Mr. Hughes would be inclined to keep his engine in the shed. The question of such exceptional circumstances was more or less one of expediency; and although it would be a serious thing to a tramway company to lose a whole day's traffic, still neither in the case of steam nor in that of compressed air would there be any consumption of corn and hay going on, as with the present system.

With regard to the system of air vessels advocated by Mr. Adamson, he believed that he himself had been the first, six years ago, to adopt that system, as shown in Fig. 5, Plate 91, which closely corresponded with Mr. Adamson's design. With regard to Colonel Beaumont's invention, the knowledge which the public had of it was not great; but it would appear that in his later efforts he had entirely departed from his original design, and certainly the departure had been in a similar direction to that previously followed by himself. Colonel Beaumont had started with six cylinders and

had now come down, as he himself had previously done, to two. He was not himself prepared to say that there would not be a great advantage in expanding the air first in one cylinder and then in the other; but the plan he had himself described he found as a matter of fact to work very satisfactorily, although he was not prepared to say that he might not make efforts to improve upon it. With regard to the question of heating the air, the great importance of doing so, from a mere dynamical point of view, was so evident that no one could ignore it. There was perhaps no case, in the whole range of mechanical engineering, in which the same advantage could be taken of a given number of heat-units as in the case of a permanent elastic fluid such as compressed air. In the case of steam, a large part of the available heat was expended in converting the water into the condition of an elastic fluid before using it: while with air that elastic fluid was found in the reservoir of nature ready made. But, as far as his experience had hitherto gone, the whole question turned upon the point whether it was expedient or not to heat the air in an engine of that particular sort. The importance of doing so, with a view to fuel economy, he did not for a moment dispute; but if the effect of using a more complicated apparatus, and a higher pressure of air, led to greater expense and greater wear and tear, and if the result after all was to save the difference between one halfpenny and one-third of a penny per mile (that is, between his own figure and Mr. Adamson's), then he doubted very much if the additional expense and trouble and inconvenience would be compensated by the saving in fuel.

As reference had been made at considerable length to Colonel Beaumont's engine, he might be allowed to add the following statement as regarded the comparative economy of the two systems. In his letter to M. Bergeron, Colonel Beaumont had stated that his engine used 10 cub. ft. of air at 1000 lbs. pressure per mile run, equivalent to 660 cub. ft. of air at the pressure of the atmosphere. To compare this efficiency with that of his own car, carrying forty passengers, the following figures were sufficient. In the receivers of the car there were 140 cub. ft. of storage, charged with air at 26 atmospheres; giving a total of 3640 cub. ft. of air at atmospheric

pressure. From this had to be deducted the air left in the receivers at the end of a seven-mile journey, namely 140 cub. ft. at 9 atmospheres, or 1260 cub. ft. at atmospheric pressure. The difference, or 2380 cub. ft., divided by 7, gave 340 cub. ft. as the consumption per mile, against 660 cub. ft. required by the Beaumont engine. In the latter case there was also the inconvenience of a separate locomotive, and the additional losses of power arising from the higher pressures and the heating of the air.

He had frequently had occasion to consider the practicability of using compressed air on a large scale, for such a system as the Metropolitan Railway referred to by Mr. Tomlinson; and he had come to exactly the same conclusion, namely that, even if the system were applicable in other ways, the enormous amount of capital required, especially for ground &c., would nullify from a financial point of view any advantage that might arise from its adoption. There was of course the advantage of doing away with noxious vapours in the tunnel; but probably that would be taken into account only so far as it actually prevented persons from using the trains, not as regarded their feelings when they were using them. Hence, from an economical point of view, he was very doubtful if compressed air was applicable on such a system as the Metropolitan Railway. Certainly, if it were used on such a scale, the question of heating the air would become of paramount importance. As Mr. Tomlinson had said, it became a totally different matter from that of a small vehicle passing along a tramway, in which the competing power was not steam, but the expensive force of horses. As to the use of higher pressures, as recommended by Mr. Tomlinson, the whole question after all was a practical one. Using 1000 lbs. pressure was very fine in theory, and no doubt it would be very admirable in practice if it could be done; but he thought the experience of most engineers, in dealing even with much lower pressures, would lead them to be wary of resorting to any such pressure at all. If a vehicle could be got to work practically and economically at a lower pressure, the slightly increased advantage in the higher pressure would not be a sufficient compensation for the increased outlay. The margin in the case of a successful mechanical

motor for tramways, as compared with horses, was so great, that if he once got an apparatus upon a thoroughly sound footing, not likely to get out of order or to lead to any great expense, he should consider himself much safer than in trying to compass any special economy by means of theoretical advantages not fully capable of realisation in practice.

FIRST REPORT TO THE COUNCIL OF THE COMMITTEE ON THE HARDENING, TEMPERING, AND ANNEALING OF STEEL.

(Issued Nov. 1879, and now published by order of the Council.)

Members of the Committee:—William Anderson, Esq. (*Chairman and Reporter*); A. Paget, Esq.; R. Price Williams, Esq.; Prof. F. A. Abel, C.B., F.R.S.; P. Brotherhood, Esq.; Herr D. Chernoff; W. Hackney, Esq.; Prof. D. E. Hughes, F.R.S.; G. H. Ogston, Esq.; Prof. W. Chandler Roberts, F.R.S.; J. Vavasseur, Esq.; Prof. Alex. W. Williamson, F.R.S.

Annexed to this report is a list of the books and detached articles relating to the subject which have been examined and considered. It does not appear needful to go back to the earlier attempts in this or other countries to discover the theories of the constitution or properties of Steel, before Karsten in 1827 investigated the conditions of carbon in iron, and Jullien in 1852 deposited at the Academy of Science, Paris, a paper termed "L'Explication de la Trempe." From that period a good deal has been written, chiefly by French metallurgists.

I.—*Nature and Composition of Steel and Cast Iron.*

Karsten in 1827 says that carbon is contained in iron in three different ways:—(1.) As free carbon or graphite. (2.) Combined with the whole mass of iron. (3.) In the state of polycarburet, dissolved in the mass.

In 1852 Jullien advocated, if he did not originate, the theory that iron and carbon do not combine (as true chemical combinations), but that the compounds formed by the two substances are what he terms "solutions," or, as we should translate it into English, only mechanical mixtures. Following Karsten, Berzelius, and others,

he holds that amalgams and alloys are definite combinations dissolved in excess of one of the components. He defines "combination" to be a union of elements in definite proportions, the resulting body being different from either component and from any of their other definite combinations. "Solutions," or mechanical mixtures, on the other hand, may occur in any proportions, and the resulting mixture participates in the properties of each component in proportion to its quantity.

Your Committee find it difficult to acquiesce in the latter portion of this statement. For example, the addition of increasing proportions of tin to copper results in producing harder compounds, instead of softer. Under certain circumstances the addition of a small proportion of tin to cast iron greatly increases its hardness.

BARBA adopts Jullien's view, and defines steel to be a solidified solution of carbon in pure iron: (Les aciers sont des dissolutions solidifiées de carbone dans du fer chimiquement pure.)

OSBORN seems to think that carbon exists both in a combined form and uncombined, disseminated in the latter case as graphite; but he does not define clearly what he means by the word "combined."

CARON considers the union of the two substances to be a mixture. GRUNER takes the same view.

ÅKERMAN adopts the view that carbon occurs both in combination and as graphite; and also the view of Rinman, that combined carbon may be partly intimately combined, when it may be called "hardening carbon," and partly incompletely combined, when it may be called "cement carbon." He does not define what he means by combination, whether in definite proportions or not.

Your Committee have not found any modern author holding the opinion that the various combinations of iron with carbon, and with other substances found in steel and cast iron, are definite chemical unions with excess of either one or other of the component bodies. The elaborate evidence adduced by Jullien, which does not appear to

have been combated, makes it highly probable that steel and cast iron are only mechanical mixtures of carbon and some other substances in pure iron.

II.—*Quantity of carbon in steel and cast iron, and its state.*

Barba considers that the solution of carbon in molten iron follows the ordinary laws of solution, that is:—

(1.) The quantity of carbon which iron can contain in solution increases with the temperature.

(2.) By slow cooling a part of the carbon separates from solution and is brought into a state of mixture.

(3.) With rapid cooling, or sufficient exterior pressure, the greater part of the carbon remains in "solution;" rapid cooling acting by the pressure it produces; and, if the carbon is merely mixed, exterior pressure producing solution more or less complete according to the intensity of the pressure.

(4.) The temperature at which steel solidifies decreases as the quantity of carbon it contains augments.

He remarks that experimental demonstration is wanting to show that pressure is favourable to preserving "solution" when cooling.

Osborn says that rapid solidification favours the retention of carbon in the combined state, and by that means it is possible to change grey cast iron into white.

Jullien states (1852) that the properties which the solutions of carbon in iron exhibit are due exclusively to the rate at which the hot solutions are cooled. Following Karsten he says that the liquid solutions of carbon in iron are homogeneous, because rapidly cooled solid "solutions" are found to be so. He considers that:—

(1.) Melted cast iron is a solution of liquid carbon in liquid iron.

(2.) Grey and soft cast iron is a solution cooled slowly, and converted into a mixture of mild steel and amorphous carbon or graphite.

(3.) Grey cast iron heated cherry-red and plunged into cold water is a mixture of hardened steel and graphite.

(4.) White cast iron is a solution cooled rapidly, and consists of a mixture of crystallised carbon in amorphous iron.

(5.) White cast iron reheated, while protected from the atmosphere, and become grey and soft, is grey and soft cast iron.

(6.) White cast iron heated in contact with air, and grey or white iron reheated in closed vessels in a cement of metallic oxide, become mild steel.

(7.) Steel heated cherry-red is a mixture of liquid carbon in solid iron.

(8.) Mild steel is a mixture of amorphous carbon in iron either amorphous or crystallised.

(9.) Hardened steel is a mixture of crystallised carbon in amorphous iron.

He further states that iron absorbs carbon at temperatures ranging from cherry-red to welding heat, and up to a quantity equal to 5·25 per cent. of the mixture; that the properties of steel approach those of iron in inverse proportion to the quantity of carbon; and that the presence of carbon not only increases the fusibility of the alloy, but communicates to it, in certain cases, properties belonging exclusively to crystallised carbon or diamond.

He also states that the temperature of fusion of grey cast iron is higher in proportion as the quantity of graphite is greater, while the temperature of solidification is lower in proportion as the quantity of dissolved carbon in the fluid mass is greater. The lower therefore the temperature of solidification of grey cast iron, the higher is its point of fusion; it is only steel that has the same temperature of fusion and solidification. This property of cast-iron is common to many bodies, such as bismuth, tin, sulphur, and water, under favourable conditions of cooling.

Caron states that steel, if hardened by being heated to redness and cooled rapidly, and then dissolved in strong hydrochloric acid, leaves no residue; that the same steel, if raised rapidly to a red heat, and allowed to cool slowly, will, if dissolved as before, leave a residue of carbon, which dissolves on being heated; and that the same hardened steel, if annealed by being kept at a red heat for

a long time and allowed to cool slowly, dissolves more easily, but leaves a residue of carbon insoluble even in hot acid.

The conclusions he draws are, that in the first case the iron and carbon are intimately united and dissolve together; in the second case the union is not so intimate, therefore the more soluble body dissolves first, and the carbon, which is not quite modified, yields last; and in the third case the carbon is free, and shows it by its property of resisting acids.

What Caron terms a solution of iron or carbon in hydrochloric acid appears to your Committee to be probably a "double decomposition." Carbon is very unchangeable, resists the action of acids and alkalies, and bears the most intense heat in close vessels without fusing or undergoing any perceptible change. Baumhauer confirms these statements with respect to diamond, and relates the experiments by which they are proved. He also states that a diamond, when heated for a long time to whiteness in carbonic acid gas, showed prismatic colours on some of its facets.

Åkerman states that graphite is only mechanically incorporated in pig iron, and can be separated by dissolving the iron in acid. The combined carbon, on the other hand, when the iron is dissolved in boiling hydrochloric acid, escapes as carburetted hydrogen, provided proper attention is given to the dissolving process, so that the boiling commences almost immediately after the addition of the iron to the acid, and is continued uninterruptedly for a sufficient length of time without access of air. When dissolved in cold acid, and warmed a little time after, a part of the combined carbon remains as a black residue, especially if air has ready access. He also quotes Caron's and Rinman's statements with respect to the solution of steel in acid.

Gruner states that each temperature corresponds to a maximum of solubility, and that this solubility rises and falls both in the fluid and solid states. Whenever a carburetted iron (steel or cast iron) cools slowly, an intimate mixture of iron and particles of graphite is produced, as in the case of untempered steel and grey cast iron.

When carburetted irons are cooled quickly, the separation of carbon is rendered impossible for want of time, and carbon remains dissolved in the iron at ordinary temperatures; saturation then results. The mixture becomes hardened steel when the proportion of carbon is below 1·5 per cent., and white cast iron when above that quantity.

III.—*Substances other than Carbon entering into the composition of Steel.*

Dr. Siemens is of opinion that high-class steel should contain only iron and carbon: the hardness, temper, ductility, elasticity, toughness, and strength depending upon the relative proportion of these two elements. But as it is almost impossible to produce such pure metal, other substances, which must however be considered as impurities, have to be admitted: these impurities have a certain influence in rendering steel hard. or rather in making it brittle; thus if phosphorus is allowed, a certain dose of manganese has to be added to prevent cold-shortness, and a smaller quantity of carbon must be used. Manganese is a treacherous element in steel, as its distribution is not uniform, and thus a homogeneous compound is not produced.

According to Fernie, a sample of Krupp steel contained 1·18 per cent. of carbon and a trace of manganese, and a sample of American steel 0·23 per cent. of carbon and no manganese; the latter constituted soft metal fit for fire-boxes. Frémy (1864) advanced the theory that nitrogen was an essential component of steel; that steel was, in fact, a nitro-carburet of iron. Caron however considers it proved that all kinds of iron contain feeble quantities of nitrogen, 0·00011 per cent., and considers that it must be looked upon as an impurity just like silicon, sulphur, and phosphorus. According to F. C. G. Müller, it has been proved that hydrogen, nitrogen, and carbonic oxide are to be found in the pores of Bessemer and Siemens-Martin steel.

Cyanogen, tungsten, chromium, platinum, silver, and other substances have been mixed with steel with a view to give it certain high qualities; but Chernoff, Dr. Siemens, and many others are of opinion that true steel is a mixture or combination of carbon and pure iron

alone, and that all other substances are impurities necessarily injurious in pure steel, though sometimes apparently beneficial if they exclude or neutralise more injurious substances. BOMAN states that Bessemer steel No. 1 (which is necessarily impure), containing only 2 per cent. of carbon, is hardly malleable; while ANOSOFF found that the hardest "boulat" (the sabre steel of the Tartars), which is perfectly pure, retained its malleability though it contained 3 per cent. of carbon.

IV.—*Hardening of Steel.*

JULLIEN holds that carbon in contact with iron at cherry-red heat becomes liquid, and is absorbed like water in a sponge, like oxygen in liquid silver, or like gas in porous bodies; cooled slowly, the carbon becomes amorphous, and the steel becomes soft as iron; cooled quickly, the carbon crystallises to depths proportioned to the energy of cooling, and steel becomes diamond set in iron.

In your Committee's opinion this theory, even if it accounts for the hardening of steel, does not account for tempering. What takes place when hardened steel is heated and passes through all the gradations of hardness indicated by their characteristic colours?

JULLIEN quotes Berzelius as stating that when a saline solution, saturated or not, is allowed to cool quickly almost to the congealing point, the periphery which is first cooled becomes less saline than the centre; until at last, when the entire mass has solidified, the dissolved salt is found concentrated in the centre. From this fact he infers that two bodies dissolving each other, and preserving their independence in solution, must produce solid compounds of varying properties according to the rate at which cooling takes place.

Furthermore all solid bodies are susceptible of two different molecular structures, dependent on the rate of cooling from the fluid state; but this rate of cooling does not produce the same results on all. Thus gold, silver, and copper, if cast in chills, yield a fibrous structure, while, if cast in sand moulds, they exhibit a crystalline fracture; and the fibrous structure can be changed into the crystalline by a temperature short of fusion. Carbon and glass behave quite

otherwise. Diamond, exposed sufficiently long to a high temperature in a covered crucible, becomes amorphous or graphite : hence it may be concluded that, if it could be taken liquid and subjected to energetic cooling, it would crystallise; while under slow cooling it would become graphite. Glass, taken liquid and submitted to energetic cooling, crystallises; but when annealed, it becomes amorphous or ceramised. Rupert's drops, which are transparent crystallised glass, become opaque if heated for a long time. He therefore considers that a mixture of iron and carbon, if cooled quickly, becomes hard because the carbon crystallises into diamond; while, if it is cooled slowly, the carbon remains amorphous and comparatively soft. Chilled grey cast iron has a mottled band between the chilled and unchilled parts; this is the zone where the carbon is partly crystalline and partly amorphous.

Gruner considers that carbon is dissolved in hot iron : that when cooled slowly the carbon has time to separate as graphite, but when cooled quickly there is no time for separation ; and white chilled iron instead of grey cast iron is the result. Soft and hard steel show a similar difference though to a less degree.

Barba and Åkerman consider that the compression resulting from rapid cooling is the cause of a greater amount of carbon being retained in solution, and prevented from separating as graphite.

Your Committee find it difficult to accept this theory, because the compression of the internal portion of a piece of steel is caused by the contraction of the outer layers; and these therefore must be stretched, as indeed it is well known that they are. But in hardened steel the outer layers, which were most energetically cooled, are the hardest, although they must have been, and probably are, in a state of tension. Åkerman however considers that compression, or forcing together of the particles, the amount of which is dependent on the rapidity of cooling, produces hardening; and that the intensity of this hardening depends on the compactness of the material and its limits of elasticity. By way of proof he states that cold-working, rolling, and wire-drawing produce similar results.

V.—*The molecular changes that occur in hardening, tempering, and annealing.*

The theory announced by Chernoff in 1868 to the Imperial Russian Technical Society appears to explain in a satisfactory manner the molecular changes that take place in steel when subjected to changes of temperature. His view is that :—

(1.) There is a certain temperature *a*, such that steel of whatever quality will not harden if heated to any temperature below *a* and energetically cooled.

(2.) There is some higher temperature *b*, above which steel changes from the crystalline to the amorphous condition.

(3.) If heated to a temperature between *a* and *b*, steel may harden, but does not change its structure whether cooled quickly or slowly.

(4.) If heated above the temperature *b*, and up to the melting point, steel has a wax-like structure, is incompressible, and tends to crystallise into large crystals if left to cool slowly undisturbed, but into smaller crystals if hammered or if rapidly cooled.

Fine grain is essential to good tough steel; hence, by heating up to the temperature *b*, so as to produce the amorphous condition, and then cooling suddenly to below *a* in oil or water, good steel can be obtained. The temperatures *a* and *b* vary with the nature of the steel.

Chernoff illustrates his views by reference to the behaviour of alum undergoing crystallisation; and the close reasoning of his remarkable paper carries a strong conviction of the correctness of the views he advocates. There are abundant illustrations of his theory to be found in the many writers on steel who have been consulted. Thus Hackney states that quenching mild steel improves its tenacity and ductility. Riley expressed an opinion that it was not so much the percentage of carbon as the way in which the rails had been cooled that should be taken into consideration, when two rails of the same chemical composition differed in hardness. Barba states that annealing should not be done at too high a temperature, otherwise the steel will crystallise with slow cooling, will lose elasticity, and become

what is ordinarily called "burned." Caron states that "burned" iron can be restored by raising it to a white heat, and then placing it under the rapid action of a steam hammer. Chernoff also describes and explains the case of a "burned" ingot of steel, which he treated in the above manner and restored to its proper condition. Osborn states that steel has a remarkable property of remaining in a pasty condition through a considerable range of temperature below its melting point; and that bar-iron acquires a largely crystalline structure when exposed for a long time to heat considerably below fusion.

Professor Gore in 1869, and subsequently Professor Barrett in 1873, drew attention to certain anomalies that occurred in the expansion and contraction of iron wire: and in 1877 Professor Norris published the results of his experiments on the same subject, which appear to confirm Chernoff's theory in a remarkable manner. In cooling a strained iron wire from redness, it was found that the contraction due to cooling was, at a certain point and for a limited period, changed into an action of elongation. In good iron wire this irregularity could not be detected, but in hard wire and steel it was very apparent. The wire has to be raised to a very high temperature before the temporary elongation during cooling can be seen; and it does not take place if the wire is heated only just beyond the temperature at which it occurs. Professor Norris's researches have led him to the following conclusions:—

1. "That in steel, and in iron containing free carbon, there is a contraction or shortening which is excited by heat, and which proceeds simultaneously with the dynamical expansion and masks its true amount. This is divisible into high and low-temperature contraction.

2. "That similarly there is a cooling expansion or crystallisation, which comes in during the dynamical contraction and masks its true amount.

3. "That these effects, due to crystallisation and decrystallisation, are the causes of the so-called 'kicks,' or temporary contractions and expansions, which occur during the heating and cooling respectively of the steel.

4. "That the low-temperature contraction and cooling expansion are due to decrystallisation and crystallisation, which occur during the acts of heating and cooling; while the 'kicks' themselves are simply the thermal effects associated with these changes, and are proportionate to their extent.

5. "That protracted annealing, *i.e.* extremely slow cooling, brings about molecular separation of the carbon and iron. Steel in such a state contracts greatly when high temperatures are reached, producing the effects of contraction which are seen at the end of the heating, and which are due to the condensation produced by the recombination of the carbon and iron. Steel in this state is less susceptible to cooling-expansion (or crystallisation), and therefore to low-temperature contraction on subsequent heating."

It would seem that the "kicks" observed by Professor Norris probably occur somewhere in the region of Chernoff's temperatures *a* and *b*, where a change in the molecular structure of steel appears to take place according to his theory. At any rate it is plain that molecular changes of some kind do occur, and manifest themselves by altering the bulk of the metal.

It has already been stated that Müller has demonstrated the presence of hydrogen, nitrogen, and carbonic oxide in the pores of Bessemer and Siemens-Martin steel.

Edison, at the meeting of the American Association for the advancement of Science at Saratoga, in 1879, extended the observations of Döbereiner, St. Claire-Deville, Troost, Faraday, and Graham; and not only applied the facts ascertained to explain the destruction of refractory metals, such as platinum and iridium, under long-continued high temperatures, but discovered the means of overcoming those defects, which had proved a serious hindrance to the extension of electric lighting. Edison noticed that the effect of incandescence on wires was to produce, all over their surface, innumerable fine cracks. When the incandescence was maintained for twenty minutes, these fissures became so enlarged as to be visible to the naked eye; and, when still further continued for several hours, the cracks united and the wires

fell to pieces. A number of experiments led him to the conclusion that the cracking of the surface of the metal is due entirely to the occluded gases, imprisoned within its pores, which become expanded and are driven out under the action of heat. By heating spirals of platinum wire gradually, by means of a transmitted electric current of periodically increasing strength, and within an exhausted chamber, the gaseous substances contained within the metal were gradually withdrawn; and by allowing the metal, in the interval between each increase of temperature, to cool down in vacuo, a series of expirations from the surface took place, alternating with a closing up and welding together again of the minute fissures through which the gentle heating in vacuo had enabled the gases to escape. By continuing this simple operation it has been found possible to change completely the physical character of metals; increasing their hardness and density to an extraordinary degree, and raising their points of fusion so high that they are perfectly unaffected at temperatures at which most substances would be melted and even volatilised. A spiral of ordinary platinum at a white heat softens, and loses its elastic and rigid character; but platinum, after having been treated in the manner above described, becomes as rigid as steel, and as homogeneous as glass; and retains these properties when glowing under the most intense incandescence. The metal so transformed cannot be annealed by any known process.

It appears to the Committee that the expulsion of the gases contained in the body of the metals may have the effect of bringing the ultimate atoms closer together, increasing thereby the force of their cohesion, and consequently resisting more strongly any rearrangement that would be necessary in annealing. It would appear also that the existence of gases in the pores of metals is an attribute of their normal states; and that the expulsion of the gases increases hardness and necessarily raises the melting point on account of the stronger cohesion of the atoms. May it not be that the sudden contraction in hardening steel has the effect of expelling occluded gases; that subsequent tempering, by raising the temperature, has the effect of permitting a fresh absorption; and that the iridescent colours

which accompany tempering are due to the change of surface caused by the infiltration of gases?

Another view is that the mere heating of steel to the proper temperature for hardening is sufficient to expel a portion of the gases, which are kept out by sudden cooling, and are slowly reabsorbed in tempering. Graham states that platinum at a low red heat will absorb four times its volume of hydrogen, and that palladium condenses more than 600 times its volume of hydrogen at a temperature below that of boiling water. May not steel therefore possess analogous properties with respect to some of the gases constituting the air? May it not absorb these more freely as the temperature of tempering rises, and so gradually become restored to its original softness?

VI.—*Directions in which further investigation appears to be needed.*

1. To investigate whether Edison's theory can be applied to the explanation of the hardening and tempering of steel; and to ascertain by experiment whether absorption and expulsion of gases take place.

2. To determine by analysis whether any chemical difference exists between the outer and inner layers of a piece of hardened steel, which before hardening was of homogeneous structure.

3. To ascertain whether there is any connection between Chernoff's theory and Norris's observations on the contraction and expansion of wires.

Signed on behalf of the Committee, 5 Nov., 1879,

W. Anderson,

Chairman and Reporter.

APPENDIX.

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COMMITTEE ON THE HARDENING, ETC., OF STEEL.

MEMORANDUM ON RESULTS OF PRELIMINARY EXPERIMENTS MADE WITH THIN DISKS OF STEEL.

By Professor F. A. ABEL, C.B., F.R.S., Hon. Mem. Inst. C. E.

(*Published by order of the Council.*)

Two series of disks have been supplied to me for purposes of comparative examination, by Mr. Arthur Paget, of Loughborough.

The first series, received in May 1881, comprised six sets of three disks each, the nature of the several sets being described as follows:—

1. As received from cold rolling.
2. Annealed.
3. Hardened in water.
4. Hardened between cold plates.
5. Hardened between cold plates and tempered to straw colour.
6. Hardened between cold plates and tempered to blue colour.

The plates were 2·5 in. diam. and 0·01 in. thick.

This series was chiefly employed for experiments of a preliminary character, partly with the object of deciding upon the methods of examination to be adopted, and partly with a view to ascertain whether it might be possible to obtain any insight into the *structure* of the steel in its different conditions, as presented by these disks.

The surfaces of the disks were in every instance carefully cleaned, by washing with ether; those which were employed for purposes of analysis were, moreover, rubbed bright with very fine emery-flour.

Samples of the disks described as "hardened," "tempered to straw colour," and "annealed," were submitted to the very gradual

solvent action of a chromic acid solution (prepared by mixing a solution of potassium bichromate, saturated in the cold, with $\frac{1}{20}$th of its volume of pure concentrated sulphuric acid). Several devices were tried for the purpose of so exposing the pieces of steel to the action of the liquid that any portions remaining, after the process of solution was complete, should retain the position they held before the rest was eliminated. But, however carefully the liquid was afterwards removed, it was found impossible to avoid disturbing the portions of the disks which had remained insoluble, and which, in some instances, were very small in amount.

The "annealed" steel was not attacked by the liquid for about seven hours after immersion: it then passed into solution slowly, with very little evolution of hydrogen.

The "straw-tempered" steel began at once to dissolve, with considerable disengagement of gas; and the "hardened" steel dissolved somewhat less rapidly, also with disengagement of much gas.

When the action of the solvent was complete, the "hardened" sample was found to have left a very small quantity of a black substance, which, under the microscope, did not appear to present a decided graphitic structure. The "straw-tempered" sample furnished scarcely any residue; there were however a very few spangly particles and black thin filaments, which, under the microscope, presented a somewhat graphitic appearance. A considerable quantity of black matter was furnished by the "annealed" sample, and this presented, under the microscope, the appearance of beautiful spangles.

This residue from the annealed steel was boiled in a solution of potassium hydrate (sp. gr. 1·1), and then in dilute hydrochloric acid; a very appreciable amount of black matter still remained, presenting when magnified a distinct graphitic appearance, though the particles were not so brilliant as the original residue.

It was observed that some of these undissolved particles were attracted by the magnet: this pointed to their being a carbon-iron combination, and this fact was thoroughly established by further experiments, to be presently described.

Disks of three varieties of steel, viz., "hardened between cold plates," "ditto, tempered to a blue colour," and "annealed," were exposed for two hours to the action of 100 cubic centimetres of a warm solution of hydrochloric acid (sp. gr. 1·13). The hardened sample dissolved entirely; the blue tempered steel left a very small quantity of black residue; the annealed disk furnished a considerable quantity of residue of similar appearance. These residues were first washed with water, and afterwards with alcohol, ether, and water successively; they were then digested with potassium-hydrate solution on a water bath for several hours. The portions remaining insoluble were washed with water, and treated with concentrated hydrochloric acid. Of the residue from the blue tempered steel, only a minute quantity, of a black colour, remained after this treatment; the residue from the annealed sample furnished a small quantity of flocculent light-brown matter.

The *total* amount of carbon was determined in another disk of each of the above three descriptions of steel, the process employed being that known as the copper-chloride process, which has been used by me extensively for many years, and has been found to be thoroughly trustworthy.

The percentages of carbon furnished by the three samples were as follows:—

Hardened between cold plates . . .	0·786 per cent.
Ditto, and tempered to a blue colour .	0·815 „
Annealed	0·170 „

On these results being communicated to Mr. Paget, I learned from him that the disks with which he had supplied me were made from two strips taken from the same bundle, and, so far as he was aware (and indeed almost certainly), the entire bundle was originally cut, before the cold and cross rolling, from one and the same sheet.

This being so, the great difference between the proportion of carbon in the annealed sample, and the proportions in the hardened and tempered samples, would appear (if not purely accidental) to be due to the different treatment to which the steel had been subjected.

The *hardening* process was described to me by Mr. Paget as follows. The disks to be hardened were placed between two *cast*-iron blocks, one being recessed to receive the plates, and the other perfectly flat. These blocks were equally heated to a bright red; a disk was then placed between them, and allowed to remain there until thoroughly and equally heated; it was then instantaneously removed, and as quickly as possible caught and pressed between two cast-iron surface-plates. In submitting the disks to the *annealing* process, they were bolted between *wrought*-iron plates $\frac{3}{8}$ in. thick, and these were then enclosed in a thin sheet-iron box (5 in. square by 2 in. deep). This sheet-iron box was placed in the centre of a cast-iron box (about 15 in. $\times$ 6 in. and about $\frac{3}{4}$ in. thick). The spaces between the two boxes were filled up with "flue-dust" (*i.e.* thoroughly burnt soot taken from the flues of a boiler near to the fire end). The whole apparatus was afterwards heated in an annealing furnace to a bright red heat, sufficient to scale the cast-iron box, but not sufficient to fuse it. The fire was then slackened off, banked up with ashes, and the box left in the furnace undisturbed for twenty-four hours.

That the annealing treatment, carried out as above described, has the effect of reducing the proportion of carbon in very thin plates of steel, which are exposed for some time to a high temperature in close contact with masses of wrought iron, appears to be demonstrated by these results; but it may be open to question whether the very great difference between the proportions of carbon in the particular hardened and annealed disks submitted to analysis was entirely ascribable to this cause.

No disks of this first series of samples remained on hand; I was therefore unable to make further carbon-determinations with the view of obtaining comparative results. But Mr. Paget was so good as to furnish me, in August 1881, with a second series of disks, with some of which I have been able to examine further into the question of the difference in the total proportion of carbon contained in samples of the *same piece* of metal, hardened and annealed by the processes above described; and also to obtain a few other results of interest, by working in the direction indicated in the first part of this memorandum.

The second series of samples received from Mr. Paget were described as follows:—

Disks numbered 1, 4, 7 and 10, representing the metal as received from cold-rolling.

Disks numbered 2, 5, 8 and 11, annealed.

Disks numbered 3, 6, 9 and 12, hardened.

The dimensions of these disks were the same as those of the first series. They were all of them cut out of one and the same strip of metal; the disks 1, 3, 5, 7, 9, 11 were ranged along one edge of the strip, and the disks 2, 4, 6, 8, 10, 12 along the other edge. The weight of each disk was about 6·5 grammes.

Of the annealed disks, Nos. 2 and 11 were those which, during the annealing process, were *in contact* with the wrought-iron plates.

No. 6 disk was devoted to the determination of the proportion of *silicon* contained in the metal, which was found to amount to 0·20 per cent.

The *total* percentage of carbon was estimated in one disk of each kind; but a second disk of the "annealed" series, an *inside* disk, was also examined, to compare it with the metal which had been annealed in immediate contact with the wrought iron. The following results were obtained:—

With Disk	No. 1, (cold rolled) . . .	1·108	per cent. of carbon.
„	No. 3, (hardened)	1·128	„ „
„	No. 5 (annealed inside disk).	0·924	„ „
„	No. 11 (annealed outside disk)	0·860	„ „

It will be seen from these numbers that the proportion of carbon in the annealed steel was decidedly lower than in the cold-rolled and hardened samples, and that the outside annealed disk, which had been in contact with the malleable iron plate, contained somewhat less carbon than one of the inner disks annealed at the same time. The much greater difference observed in the earlier results given in this memorandum is probably ascribable to circumstances needing further elucidation.

It might be desirable, with a view to securing more thoroughly comparative samples for future experiment, to enclose the disks in blocks of *one and the same* description of metal in the hardening

and annealing processes, though probably the comparatively brief duration of contact of the disks with the cast-iron blocks, in the treatment preliminary to *hardening*, may not appreciably affect the proportion of carbon. The difference between the proportions in the hardened and cold-rolled samples is scarcely greater than might exist between two results furnished by identically the same material.

An estimation was made, in three of the disks, of the proportions of so-called *uncombined* carbon, *i.e.* of the carbonaceous residue obtained by heating the metal with dilute hydrochloric acid. The disks were immersed each in 100 c.c.'s of hydrochloric acid, sp. gr. 1·10, and a gentle heat was applied for three hours. The annealed and cold-rolled disks dissolved much more rapidly than the hardened disk; while, under treatment with the chromic acid liquor, the *annealed* disks had resisted attack for very much longer periods than the *hardened* disks. The cold-rolled disk furnished the largest amount of dark-coloured residue; that from the annealed disk was dark, but much less in amount, and the small quantity furnished by the hardened disk was of a much lighter colour.

The residues were collected upon asbestos, washed successively with water, alcohol, ether, and water, and the proportion of carbon in them was then determined, with the following results:—

No. 7. (cold rolled, as received)	0·096	per cent. of carbon.
No. 8. (annealed, *inside* disk)	0·052	,, ,,
No. 9. (hardened)	0·035	,, ,,

The difference between the proportions furnished by the annealed and hardened disks is in the direction indicated by information; the cause of the comparatively very high percentage furnished by the cold-rolled disk needs elucidation.

The promise of instructive results, held out by the treatment with chromic acid liquor in the earlier experiments, led me to pursue this mode of investigation with three disks of the second series. The carefully cleaned disks were supported upon small circular trays, or sieves, made of platinum gauze, suspended in separate baths of the chromic acid liquor, 500 c.c.'s of which were used in each case —a quantity considerably in excess of that needed for the complete

oxidation of the iron contained in a disk. The baths were at the atmospheric temperature at starting. The following results were observed.

No. 4 disk, from *cold rolling*.—The solution of the metal began at once, and after a short time sufficient gas was evolved to lift a part of the disk to the surface of the liquor. At the end of three and a half hours the temperature of the latter was 76°·3 Fahr., while that of the surrounding air was 65° Fahr. The experiment was left undisturbed for five days, after which there remained upon the sieve a small quantity of black particles, which were attracted by the magnet, and presented a spangly appearance under the microscope, though not so pronounced as in the case of No. 2 disk.

No. 2 disk, *Annealed*.—The solution of the metal did not commence until after the lapse of five hours, the liquor remaining at that time quite bright red; its temperature after the lapse of three and a half hours was 65°·5 Fahr., that of the air being 65° Fahr. Afterwards the action proceeded slowly. After the lapse of five days a large quantity of black scaly matter remained upon the platinum support; it was attracted by the magnet, and presented a very spangly appearance under the microscope.

No. 12 disk, *Hardened*.—The metal was at once attacked; the disk was speedily lifted to the surface of the liquid by the gas generated, and had to be gently pressed down with a glass rod. After three and a half hours the temperature of the liquid was 75°·3 Fahr., that of the air being 65°. After the lapse of five days there remained upon the sieve a small quantity of *buff*-coloured matter, enclosing a *few* dark particles which were attracted by the magnet; these presented a spangly appearance under the microscope; the light coloured matter was evidently silica.

In each experiment a small black sediment had collected at the bottom of the vessel, having passed through the sieves. The deposit upon the sieves was washed down into the chromic liquor, and allowed to remain in it, in the cold, for a further period of thirteen days (total treatment, eighteen days' duration). The deposits were then collected upon purified asbestos plugs, in the tubes in which they were to be burnt; they were washed with

water, alcohol, and ether, dried, and burnt in oxygen in the usual manner. The proportion of iron in the insoluble matter was estimated, in each case, after the combustion of the carbon. The following numbers represent the proportions of carbon and iron furnished by the analyses of these residues, calculated upon 100 parts of the disks employed :—

	Carbon.	Iron.
No. 4. (from cold-rolling) . .	1·039 . .	5·87
No. 2. (annealed *outside* disk) .	0·830 . .	4·74
No. 12. (hardened)	0·178 . .	0·70

On comparing the amounts of carbon contained in these residues with the percentages of total carbon in the corresponding disks from the same strip of metal, it will be seen that the chromic acid treatment may be said to have eliminated *practically* the whole of the carbon from the cold-rolled disk in the form of a carbon-iron compound; and that, from the annealed disk, an even more complete elimination of carbon in that form was effected. Thus:—

	Carbon by direct determination.	Carbon in residue from chromic treatment.
No. 1. Disk, cold rolled, gave .	1·108	
No. 4. „ „ „ .	— . .	1·039
No. 11. annealed, outside disk	0·860	
No. 2. „ „ „	— . .	0·830

On the other hand, only about one-sixth of the total carbon was eliminated from the *hardened* disk, in the solid form, by the chromic treatment. In the latter case too the proportion borne by the carbon, in the residue, to the iron, was decidedly greater than in the residue from the other two descriptions of disks, as will be seen by the following statement of the ratios given by the analytical results :—

	Carbon.	Iron.
No. 4. Disk, cold rolled	1 . .	5·64
No. 2. „ annealed	1 . .	5·72
No. 12. „ hardened	1 . .	3·93

It is interesting to observe that in the case of the annealed and

the cold-rolled disks the ratios correspond very closely indeed; they also correspond closely with the proportions of the elements in an iron-carbide having the formula $Fe_6 C_5$.

That the chromic treatment was complete in these experiments, the whole of the iron having been dissolved which was not fixed by the carbon, is beyond doubt. The three experiments were conducted exactly alike and side by side, and the digestion of the eliminated iron carbide in excess of the chromic solution was a very protracted one.*

The small proportions of carbon separated from the annealed and the cold-rolled disks by treatment with hydrochloric acid of sp. gr. 1·1, appear to show that the *carbide*, which can be eliminated from the steel in those conditions, is decomposable by that acid, the iron being dissolved and the carbon escaping in combination with the hydrogen. No more disks were at the time available for the purpose of ascertaining this, by direct experiment with residues obtained by the chromic treatment.

So far as it has been possible to carry these experiments, the results they have furnished appear to warrant the belief that, in steel which has been gradually cooled, the carbon exists entirely, or nearly so, in the form of a very definite iron compound rich in carbon,

* Since the preparation of this memorandum, the following additional experiment has been made with a disk from cold rolling (No. 10), which remained in hand. The piece of metal, weighing 6·2 grammes, was placed in 500 c.c. of the same chromic solution prepared for the previous experiments, and an additional quantity of 40 grammes of concentrated sulphuric acid was added. The solution of the metal commenced at once, with evolution of gas; at the end of 24 hours it was complete, a quantity of heavy black powder remaining. This was left in the solvent for 9 days; when examined at the end of that period it was found to be attracted by the magnet. Analysis showed it to contain carbon and iron, in the proportions of 0·84 of carbon and 1·104 of iron in 100 parts of the metal. This result appears to show that, in the presence of a very considerable excess of sulphuric acid, the carbide, separated in the first instance from the metal, does not resist the action of the chromic liquor; but that, while the iron is dissolved, the carbon does not escape as gas to any large extent. It is proposed to carry the experiments further in this direction, when fresh material has been obtained.

disseminated throughout the mass, being eliminated from the iron, during the process of cooling, in a more or less distinctly crystalline form; that the carbide is again assimilated by the metal when it is raised to a very high temperature; and that, if the metal be suddenly cooled, there is no time for the elimination to take place, and the carbon (or carbide) remains dissolved in the metal, more or less completely, according to the degree of rapidity with which the cooling process is carried out.

Further experiments appear desirable, with a view to confirm, or otherwise, the results described in the foregoing; and, should they be confirmed, to extend the investigation, in the direction commenced with annealed and hardened steel, to steels of different temper. It is also possible that, by modifications of the mode of experiment hitherto pursued, more decisive information may be elicited regarding the distribution of the carbide through samples of steel, alike in ultimate composition, but presenting distinct physical characteristics.

The experiments, of which the foregoing is an account, have been carried out under my direction by Mr. W. H. Deering, whose great skill in manipulation and analysis is invaluable in carrying on researches where small quantities have to be dealt with.

COMMITTEE ON THE HARDENING, ETC., OF STEEL.

RESULTS OF EXPERIMENTS MADE WITH A VIEW TO ASCERTAIN WHETHER OCCLUDED GASES PLAY ANY PART IN THE HARDENING AND TEMPERING OF STEEL.

By Professor W. CHANDLER ROBERTS, F.R.S.

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It will be remembered that the first Report of the Committee, after considering the various theories as to the causes of the hardening and tempering of steel, concludes as follows (*ante*, p. 692): —" May it not be that the sudden contraction in hardening steel has " the effect of expelling occluded gases: that subsequent tempering, " by raising the temperature, has the effect of permitting a fresh " absorption; and that the iridescent colours which accompany the " tempering are due to the change of surface caused by the infiltration " of gases? Another view is that the mere heating of steel to the " proper temperature for hardening is sufficient to expel a portion of " these gases, which are kept out by sudden cooling, and are slowly " re-absorbed in tempering. . . . May not steel therefore possess " properties analogous to platinum and palladium, with respect to " some of the gases constituting the air? May it not absorb these " more fully as the temperature of tempering rises, and so gradually " become restored to its original softness?"

There is much in the evidence afforded by recent researches to lend probability to this view; and few questions connected with the metallurgy of iron and steel are attracting more attention than

the relations between the metal and the gases with which it comes in contact during the processes of manufacture. The question of the intervention of gas in the carburisation of iron has long been recognised as one of great interest. Bergman, writing in 1781,* was the first to show that the difference between malleable iron, steel, and cast-iron depends on the amount of carbon the metal contains, and it may be well to remember that he was led to the opinion that "fixed air" could give up its carbon to iron; so that the importance of the relation between iron and gases was indicated in the researches which were the first to give us accurate knowledge as to the true nature of steel.†

Margueritte ‡ in 1865 repeated an experiment made at the close of the last century by Clouet, employing the diamond as a source of carbon. Margueritte's experiments were conducted under conditions that rendered the results unequivocal; and he showed that, although the carburisation of iron can be effected by simple contact with solid carbon, it is nevertheless true that, in the ordinary process of cementation, carbonic oxide plays an important part, which had previously been overlooked.

Graham's paper on the occlusion of gases by metals, § which appeared a year later, showed that carbonic oxide could penetrate to the centre of a mass of heated iron, and thus gave special point to Margueritte's work. The latter experimentalist had, as Graham himself observes, made the action of a high temperature very clear—the carbonic oxide being introduced into the iron at a comparatively

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* "De Analysi Ferri." Opuscula Physica et Chemica, Vol. iii., 1783.

† Kirwan, R., "Essay on Phlogiston and the Constitution of Acids," 1787, p. 140. "If a bar of soft iron be put into a crucible, well covered and luted, without any addition, and kept at a welding heat for eleven days, it will be converted into steel. . . . Here it is plain that charcoal could not penetrate through the crucible, but fixed air easily can. . . . The plumbago then clearly owes its origin to this air, as Mr. Bergman explains it."

‡ "Recherches sur l'aciération," Ann. de Chim. et de Phys., t. vi. [4,] 1865, p. 55.

§ "On the absorption and dialytic separation of gases by colloid septa," Phil. Trans., clvi., p. 436, 1866.

low temperature, while a high degree of heat is subsequently necessary, to enable the metal to appropriate the carbon and become steel. Graham's experiments showed that wrought iron occludes six or eight times its volume of carbonic oxide; and he urges that the way in which the qualities of iron are affected by the presence of a substance in no way metallic in its character—locked up in so strange a way, but capable at any time of reappearing, under the influence of heat, with the elastic tension of a gas—is a subject which metallurgists may find worthy of investigation. This suggestion has already led to important results. I hope in a subsequent communication to examine the evidence on which the present views, as to the gases occluded by iron and steel, really rest. At present I would limit myself to the question raised by the Committee, to which reference has already been made.

It appeared necessary in the first place to ascertain whether steel will "harden" when rapidly cooled in vacuo—that is to say under conditions in which access of gas is impossible. The first step is to deprive the steel, which forms the subject of the experiment, of the gases that it has already occluded during the process of manufacture; for experience has shown that it is not safe to deal with steel, in experiments of this kind, until the gases—whether pre-existing or self-produced by the reactions between the impurities it may contain—are first extracted from the metal. This however is by no means an easy matter. Six strips of steel were selected, each about 127 mm. long, 3 mm. wide, 1·2 mm. thick (5 in. × 0·118 in. × 0·047 in.): the total weight of the six being 22·5 grammes (347 grains). These were enclosed in a porcelain tube, connected in the usual way with a Sprengel air-pump. The metal was strongly heated in vacuo for twenty-six hours, at the end of which time the evolution of gas had practically ceased, and 27 cubic centimetres of gas (1·6 cub. in.), or 9·31 times the volume of the metal, had been extracted. In this particular case the gas was not analysed. The proportion of the constituent gases varies widely during the period of extraction, but in other similar cases I have found the mean composition

to be about $\frac{1}{2}$ hydrogen, $\frac{1}{3}$ carbonic oxide, and $\frac{1}{5}$ carbonic anhydride.

If a strip of the steel thus deprived of gas be heated, and cooled in vacuo, it is easy to ascertain whether hardening has been effected, and, if it has, whether the change in the steel is accompanied by a further evolution of occluded gas, which would of course destroy the perfection of the vacuum.

FIG. 1

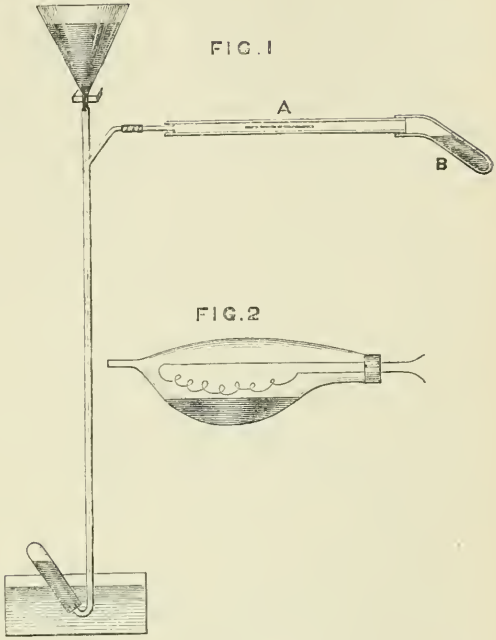

FIG. 2

The experiment may be conducted in several ways. In one case a strip of the steel above-mentioned was placed in a porcelain tube A, Fig. 1, rendered vacuous by means of the Sprengel pump, by the aid of which the vacuum could be readily maintained. At one end of the porcelain tube a bent glass tube B was fixed, which contained mercury previously boiled to free it from air. The mercury was again boiled in vacuo, in order to drive over any air it might retain, and allowed to cool. The portion of the tube containing the steel was then heated to bright redness, and, without detaching the tube from the pump, the heated metal was tilted rapidly into the reservoir of mercury, about an inch of the metal being actually submerged in the fluid. This portion afterwards proved to be of a degree of hardness that would readily scratch glass.

The end of the steel that had not touched the mercury of course remained soft. It will be obvious therefore that steel will harden under conditions in which there are no gases for it to absorb; and, as the mercury column in the pump remained undepressed, no occluded gases were evolved during the hardening. With regard to the suggestion of the Committee that the characteristic colours produced in tempering steel may be due to the absorption (as distinguished from oxidation) of gas, I would point out that hardened steel may be tempered by heating and slow cooling in vacuo, and, in the absence of air, the metal does not sensibly change colour.

On heating steel in vacuo in a porcelain tube, care must be taken to prevent contact with the siliceous walls of the tube; otherwise the carbon of the steel, as Troost and Hautefeuille have shown,* will reduce the silicate, and the consequent evolution of carbonic oxide will render it impossible to maintain a perfect vacuum. In the experiment I have described, care was taken to keep the steel from the sides of the tube by platinum studs. Before the steel was tilted into the mercury the evolution of gas had entirely ceased, and the mercury stream of the pump fell with the sharp click that indicates a good vacuum.

The experiment may be varied by heating a spiral of steel wire to redness in vacuo, Fig. 2, by means of an electric current, as Edison did in his well-known experiments on the effect of high temperatures on metallic wires. When the evolution of bubbles of gas has ceased, the apparatus is turned, so as to bring the incandescent wire in contact with mercury. The portions of the wire that touch the mercury become glass-hard, and the ends that cool slowly remain soft.

It is hardly necessary to point out that Réaumur, the great authority of the eighteenth century on the conversion of malleable iron into steel, when he published his singularly advanced work on the subject in 1722, was not aware of the importance of the part played by carbon; for he says,† "We now know that steel

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* "Comptes Rendus," 1873, pp. 482 and 562.

† "L'art de convertir le fer forgé en acier," Paris, 1722, p. 320.

"only differs from iron by being more penetrated with sulphurs and "salts." I was not aware however, until after I had made the above experiments, that Réaumur's views, as to the characteristic property which steel possesses of hardening when heated and rapidly cooled, were of so much interest; and indeed the experiments on which his conclusions were based seem to have been generally overlooked or forgotten. In the work to which I have already alluded, he says,* "As a second explanation I would suggest one "according to which the hardening depends on a substance being "driven from between the particles by heat, its return being "stopped by the water. I confess this took my fancy very much "at first. It appears natural to suspect the existence of enclosed "air, which is pressed between the particles of the untempered steel. "Where is there not air? May not this air, by tending to separate "the particles of the steel, hinder them from holding well together? "But the fire, by expanding the steel and opening the pores, drives "away this air, to which all entry is stopped when one cools the "metal suddenly, instead of letting the same air return little by "little into the steel as it gradually loses its heat." He satisfied himself that this explanation was not correct, by allowing a piece of red-hot steel to cool slowly in the *best Torricellian vacuum he could secure.* A piece of hot steel was attached to a plug fixed by a layer of wax or resin inside the top of a long upright tube nearly filled with mercury, so as to leave a small space of air surrounding the steel. The mercury was then allowed to fall, and thus produced a highly rarefied atmosphere, in which the steel was slowly cooled. On removal it proved to be perfectly soft.

The question then of the true cause of the hardening of steel remains much where Réaumur left it when he stated † that, "since the hardening of steel is neither due to the introduction of "a new substance nor to the expulsion of air, it only remains for us "to seek its cause in the changes occurring in its structure," or, it may be added, in the mode of existence of the carbon in the metal.

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* Loc. cit., p. 317. † Loc. cit., p. 319.

COMMITTEE ON RIVETED JOINTS.

EXPERIMENTS ON THICK PLATES, SERIES IX.

Report by Prof. Alex. B. W. KENNEDY.

(Published by order of the Council.)

The experiments in this series are upon single-riveted lap-joints, each with two rivets, the whole being made in $\frac{3}{4}$-in. plate, of the same general quality as the plate used in the former series (viz., Landore S. S.). The plate and rivet steel were supplied by the Landore Siemens Steel Company, and the machining and riveting (the latter done by hand) were carried out by Messrs. J. Penn and Son of Greenwich; the joints were tested by the writer at University College. The whole of the plates used in the joints were cut from one plate, 13 ft. 7 in. × 2 ft. 6 in. × $\frac{3}{4}$ in., the position of the different pieces being so arranged (Plate 94) that each type of joint might be equally affected by inequalities (if any existed) in the metal at different positions across the plate. Six sets of three similar joints each (eighteen joints in all) were made, Nos. 1233 to 1238 in Plate 94 and Table XXVI. appended; as well as fourteen specimens for tensile tests.

In the first set (No. 1233) rivets 1·1 in. diam.* were used, and the joint was proportioned according to the results of Series VIII. and the inferences drawn from it (Proceedings 1881, p. 253), so as to be equally likely to be broken by tearing or by shearing. That is, No. 1233 was designed to be the strongest possible joint with $\frac{3}{4}$-in. plate and 1·1 in. rivets. It was assumed that this was the largest size of rivet likely to be practically used with $\frac{3}{4}$-in. plate. The ratio of rivet to plate section was designed for 1·4 to 1; but in consequence of the plate being somewhat thin, it was actually 1·46 to 1. (The highest value of this ratio given by any boiler maker in the Table on pp. 293–9 of Proceedings 1881 is 0·96 to 1).

The set of joints No. 1382 will be described further on.

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* The diameters given are the diameters of the *drilled holes*.

The second set of joints in the scheme, No. 1234, was designed with a very large excess of plate area (the plate and rivet areas being made practically equal) in order to correspond more nearly to the proportions given in the Table just mentioned. The rivet area was kept as before, and about 40 per cent. added to the plate area.

In the third set of joints, No. 1235, the plate area was kept at its normal amount (as in No. 1233), and the rivet area increased by 20 per cent. by using 1·2 in. rivets instead of 1·1 in. These joints were intended to give way by tearing. They are not of course the strongest joints that can be designed for 1·2 in. rivets.

In the fourth set of joints, No. 1236, the rivet area was again brought to its normal value, and the plate area reduced by 20 per cent., so that the joints should give way definitely by tearing the plate.

In the fifth set of joints, No. 1237, the normal plate area was kept, but the rivet area reduced by about 20 per cent., so that the joints should give way by shearing the rivets.

In the last set of joints, No. 1238, the normal proportions were used, but the joints were made of pieces cut *across* the plate instead of along it.

The results of the whole series of experiments may be summarised as follows:—

The plate is exceedingly soft and ductile, and of very uniform quality. Of eight pieces tested for tenacity the average resistance was 27·27 tons per sq. in., with 27·2 per cent. extension in 10 in., and 54 per cent. extension in 2 in., a degree of ductility which could hardly have been expected in so thick a plate. The $\frac{3}{8}$-in. plate used in Series VIII. had a tenacity of 29·3 tons per sq. in., and an extension of 23·2 per cent. in 10 in. (see Proceedings 1881, Table XXIV., p. 255). *Across* the plate only two specimens could be got for determination of tenacity, and these give a mean of 26·9 tons per sq. in., with 22·3 per cent. extension in 10 in. The details of these results are given in Table XXVII. annexed.

The normally proportioned joints (No. 1233) broke by tearing the plate at an average of 29·73 tons per sq. in., or 9 per cent. in excess of the tensile resistance, but without reaching the full shearing resistance of the rivets, which had been estimated at 22 tons per

sq. in., as in Series VIII. Although the rivets had not sheared, their heads and ends had been almost torn off by the extreme bending of the soft plate; and the writer thought that probably additional strength might be obtained by making heads and ends heavier, so as to stiffen the plate somewhat, and let the full shearing resistance of the rivets come into play. Messrs. Penn kindly undertook to cut the ends off the specimens No. 1233, and re-drill and rivet them, with the heaviest rivets which they found it possible to make sound by hand. The actual average weight of the rivets in No. 1233 was 0·88 lb. each: in the new set, No. 1382, the average weight was 1·20 lb., or 36 per cent. more. The result is very striking. The plates were so much better held together that they were still unbroken when the full shearing stress of 22 tons per sq. in. was reached, and the joint broke by shearing instead of tearing. The stress in the (unbroken) plate was 32·2 tons per sq. in., or 18 per cent. in excess of the tensile resistance of plain pieces. The proportionate strength of the joint was raised from 49 per cent. to 53 per cent. of the strength of the solid plate.

The joints in No. 1234, where the plate area was increased, broke, as was expected, by shearing the rivets. These all sheared fairly, but in this, as in other cases, there was generally some sign of tearing at the head of the rivet. The rivet sheared at 21·58 tons per sq. in., the proportionate strength of the joint being only 43·6 per cent. of that of the solid plate.

The set of joints with excess shearing area, No. 1235, contains the only one which gave way both in plate and rivets, viz., No. 1235–2. The cause of this was the weakness of the rivet-heads, one of which was pushed right off, *as a ring*, unbroken, from its shank, a striking instance of the remarkable ductility of the rivet-steel. These joints were weakened by the small heads in the same way as No. 1233; and the writer suggests that they should be re-drilled and riveted with heavier rivets as the others were. The joints gave way by tearing at about 30·6 tons per sq. in. (neglecting 1235–2), when the shearing stress was only 17·8 tons per sq. in., their proportionate strength being 48·2 per cent. With heavier rivets no doubt the tensile resistance may be somewhat increased,

and the strength of the joint brought very nearly to that of No. 1233. In order to see how much stronger a joint with the larger rivets might be made, the writer suggests that the set No. 1234—4·75 in. broad—should be cut down and riveted with 1·2 in. rivets.

The set of joints made with too little plate area, No. 1236, showed just the same characteristic as the similarly proportioned joints, No. 656 in Series VIII., namely that the excess tenacity was increased by the narrowing of the bridges or necks between the rivets (see Proceedings 1881, p. 227). The joints broke by tearing, of course, but the tearing stress at fracture was 33·24 tons per sq. in, or 22 per cent. in excess of the tenacity of the plate. (In Series VIII. the excess tenacity under similar conditions reached 25 per cent.) The proportionate strength of the joint is 47·6 per cent.

The set of joints, No. 1237, made with too small rivets, naturally proved themselves weaker. They all broke by shearing, the mean shearing stress at fracture being 21·84 tons per sq. in., or practically the full resistance, unless the 1-in. rivets are proportionally stronger than the larger ones. The stress in the plates when the rivets sheared was 26·1 tons per sq. in., and the proportionate strength of the joint 45·4 per cent.

The set of joints made from pieces cut across the plate, No. 1238, proved practically identical with the similarly proportioned ones cut along the plate. They gave way by tearing at a mean stress of 29·72 tons per sq. in. in the plate, their proportionate strength being 49·6 per cent. By the use of larger rivet-heads and ends this could doubtless be raised, exactly as with No. 1233.

The bearing pressure was in all cases small (the highest only 26·45 tons per sq. in.), and therefore does not show any influence on the results.

Probably the percentages of strength all round could be increased were the riveting hydraulic instead of by hand; but with such narrow specimens this did not seem feasible, on account of the injury which the great pressure might do in squeezing the unsupported metal at the sides of the plate.

Before each joint was tested, a line was scribed across the edges of the two plates, and the point at which slipping began to be visible

was observed by the aid of a magnifying glass. The results were irregular, as might be expected, and as they were found to be in the former experiments (see Proceedings 1881, p. 228). It does not seem possible to say whether the slip observed was due to a real commencement of "giving" in the metal of the joint (either in the plates or in the rivets), or whether it was partly or wholly due to the "take up" of the rivets in the holes. Be this as it may, there is no doubt that a motion which, although very small, was still sufficiently distinct to be observed by the means mentioned above, occurred in the joints which had the largest ratio of rivet to plate area (Nos. 1235 and 1236), when the stress in the plate was about 6 tons per sq. in., and in the others at still lower loads; the lowest being in the case which most nearly resembled the proportions often used for iron joints (No. 1234), where the stress only reached 3·6 tons per sq. in. before slip was visible.

Comparing the results given in Table XXVI. with the proportions actually used in practice, as given in the Table upon pp. 293–299, Proceedings 1881, it will be seen that in no case has sufficient allowance been made in these proportions for the great difference between the shearing strength of steel rivets and the tenacity of steel plates,—that is, if the proportions were applied to steel joints. Assuming the same constants as those obtained in Series IX., and assuming that the riveting was of the same quality, the joints A and B of that Table would have a proportionate strength of only 33 per cent., D 37 per cent., F 39 per cent., and G 42 per cent. of the solid plate; instead of the 50 to 53 per cent. which can be got by placing the rivets nearer together.

In conclusion it ought to be pointed out that, although these joints were broken in the testing machine, it really seems impossible that they could have been *broken* in a boiler. The enlargement of the rivet-holes is so great that the rivets are quite free in them long before fracture occurs; so that, unless an exploding pressure could be put on with absolute suddenness, the boiler will leak all over long before anything like the breaking stress is reached in either plates or rivets.

RIVETED JOINTS.—TABLE XXVII.

Series IX.—Tenacity etc. of $\frac{3}{4}$-in. Plates used.

Test Number.	Dimensions of strips. Breadth. In.	Thickness. In.	Area. Sq. In.	Limit of Elasticity per sq. in. Pounds.	Tons.	Breaking Load per sq. in. Pounds.	Tons.	Ratio of Limit to Break.	Final Extension. In 10 in. Per cent.	In 2 in. at fracture. Per cent.	Strip cut Along or Across plate.
1239	1·750	0·729	1·275	32560	14·54	60240	26·89	0·541	27·5	53·0	Along
1240	1·751	0·730	1·278	33180	14·81	61780	27·58	0·537	27·1	55·5	,,
1241	1·751	0·731	1·280	33250	14·84	59810	26·70	0·556	27·1	54·5	,,
1242	1·750	0·732	1·281	41470	18·51	61200	27·32	0·678	25·9	52·0	,,
1243	1·751	0·724	1·268	28900	12·90	61770	27·58	0·468	27·2	54·0	,,
1244	1·750	0·731	1·279	33160	14·94	61430	27·42	0·545	27·2	55·5	,,
1245	1·752	0·730	1·279	33280	14·86	62050	27·70	0·537	28·5	55·0	,,
1246	1·751	0·730	1·278	31550	14·08	60400	26·97	0·522	27·4	51·5	,,
			Means	**33460**	**14·92**	**61080**	**27·27**	**0·548**	**27·2**	**53·9**	
1251	1·750	0·718	1·257	32770	14·63	59950	26·76	0·547	22·0	41·0	Across
1252	1·750	0·718	1·257	33740	15·06	60720	27·10	0·556	22·6	45·5	,,
			Means	**33250**	**14·84**	**60330**	**26·93**	**0·551**	**22·3**	**43·2**	

COMMITTEE ON RIVETED JOINTS.

MEMORANDUM OF EXPERIMENTS ON LAP-JOINTS, WITH RIVETS OF DIFFERENT SIZES.

By Mr. R. V. J. KNIGHT, of Greenwich.

(Published by order of the Council.)

The first experiments were on two* iron joints, double riveted, $4\frac{1}{2}$ in. wide, $\frac{7}{16}$ in. thick, with six rivets $\frac{1}{2}$ in. diameter, transverse pitch $1\frac{1}{2}$ in., longitudinal pitch, or spacing between pitch-lines, $1\frac{5}{16}$ in.

1st joint broke through rivet-holes with 18 tons, or less.
2nd „ „ „ „ „ 17 „

As the rivet-heads of these two joints were small for the holes they covered, and as the heads were a little on one side, they were considered second-class specimens; and two more joints were prepared of the same dimensions, but with rivet-heads due to a $\frac{9}{16}$ in. rivet. The following results were obtained :—

3rd joint broke through rivet-holes at $20\frac{1}{2}$ tons.
4th „ „ „ „ „ $21\frac{1}{2}$ „

These two joints were considered first-class specimens. The mean shearing stress at fracture was thus 18 tons per sq. in., and the mean tensile stress 16 tons.

Experiments were then made on four iron joints $4\frac{9}{16}$ in. wide, and $7\frac{7}{16}$ in. thick, with four rivets $\frac{11}{16}$ in. diameter, transverse pitch $2\frac{9}{32}$ in. longitudinal pitch 2 in.

* In Volume liv., "Proceedings Inst. Civil Engineers," p. 161, will be found experiments on two iron joints whose dimensions are all twice those of the above joints. They broke at $71\frac{1}{16}$ tons and $73\frac{2}{10}$ tons, the ultimate tensile strength of the iron being $21\frac{1}{2}$ tons per sq. in.

5th joint broke at connection to machine with 27 tons.
6th „ „ „ „ „ „ $27\frac{1}{2}$ „
7th joint, the rivets were sheared and plates cracked at rivet-holes with $28\frac{3}{8}$ tons.
8th „ „ „ „ „ „ „ „ „ 27 „

These four joints were considered first-class specimens. The mean shearing stress at fracture was here 18·6 tons per sq. in., and the mean tensile stress 19·8 tons, for the two last joints.*

All the above joints were cut out of one Best Best Staffordshire boiler-plate, whose ultimate tensile strength was 21·6 tons per sq. in.

The extra strength thus shown in the joints with $\frac{11}{16}$ in. rivets is believed to be due to the extra vice-like grip of the plates by the larger rivets, which prevents the plate from bending so near the centre of the rivet-hole; and also to the increased longitudinal pitch of the rivets, which diminishes the angle at which the plates are bent.

* Joints 7 and 8 were attached to the machine by clip-wedges, all the others by joint-pins.

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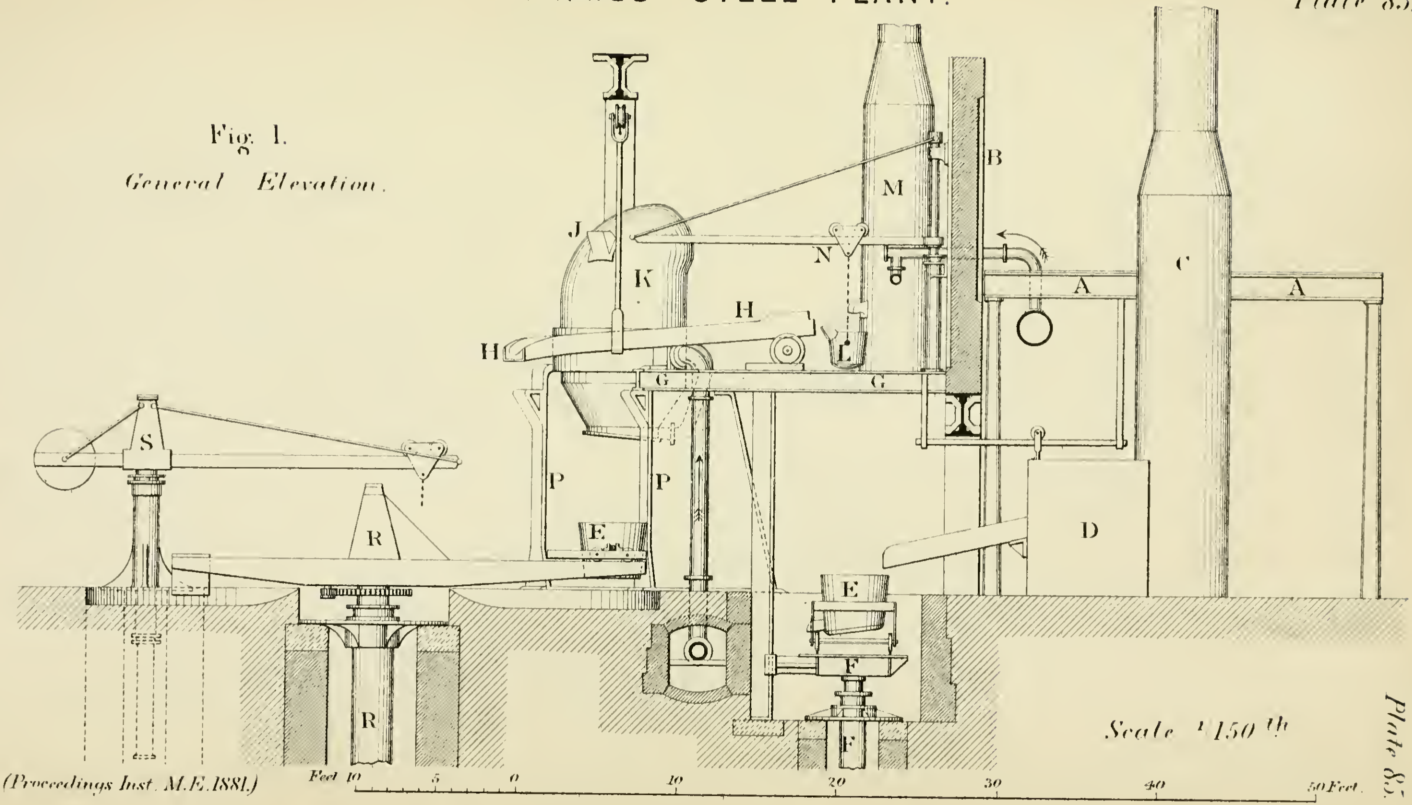
1881.

ERIMUS STEEL PLANT.

Fig. 1.

General Elevation.



Scale 1/150th

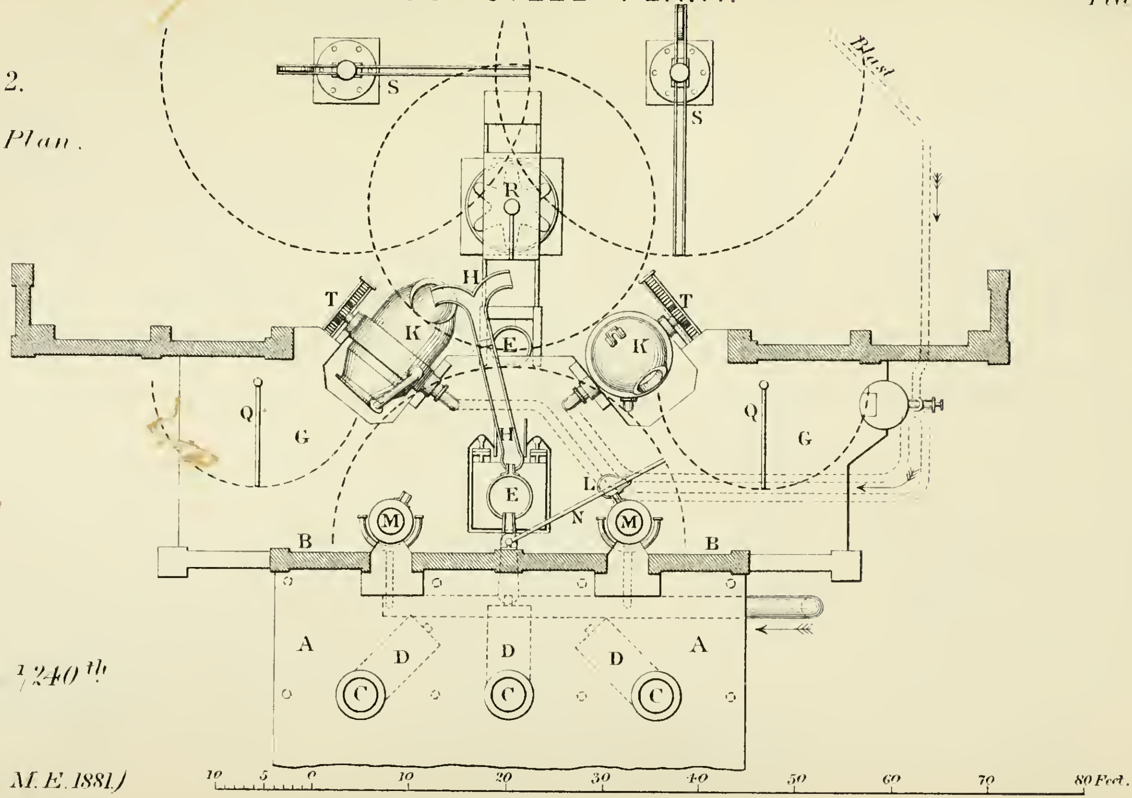
(Proceedings Inst. M.E. 1881.)

Plate 85.

ERIMUS STEEL PLANT.

Fig. 2.

General Plan.



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(Proceedings Inst. M. E. 1881.)

Plate 86.

ERIMUS STEEL PLANT

Fig. 3. *Scale 1/200th*

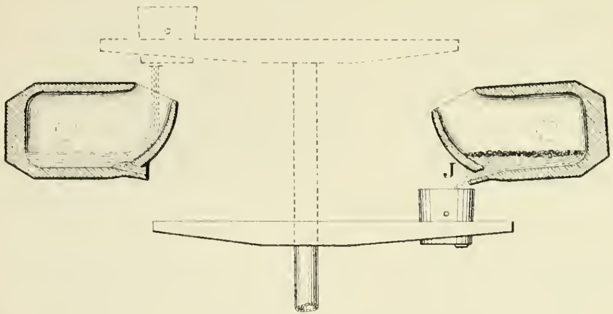


Fig. 4. *Scale 1/50th*

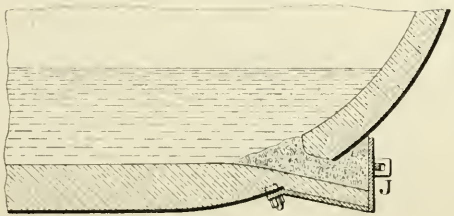


Fig. 5. *Lime Infuser.*

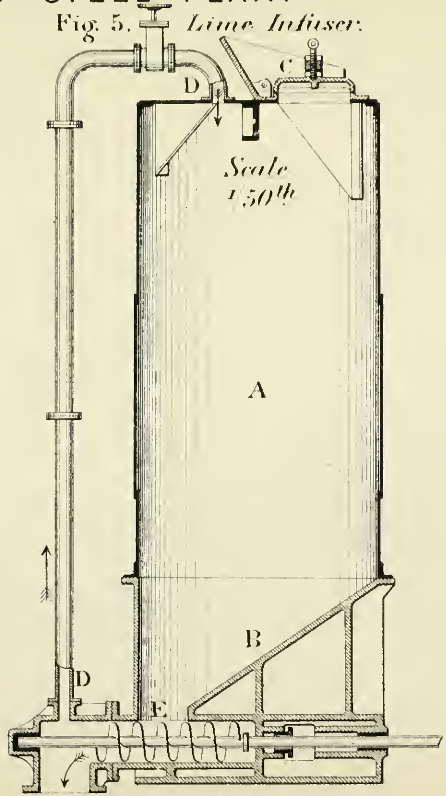


Fig. 6.

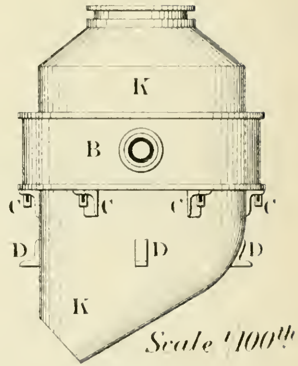
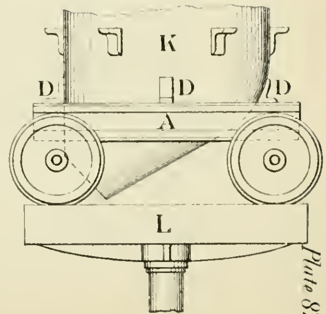


Fig. 7.

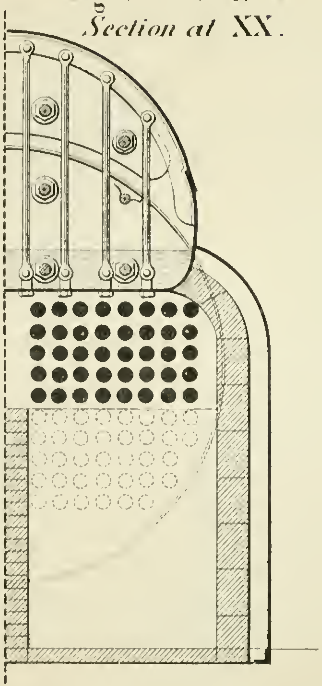


(Proceedings Inst. M. E. 1881.)

Plate 87.

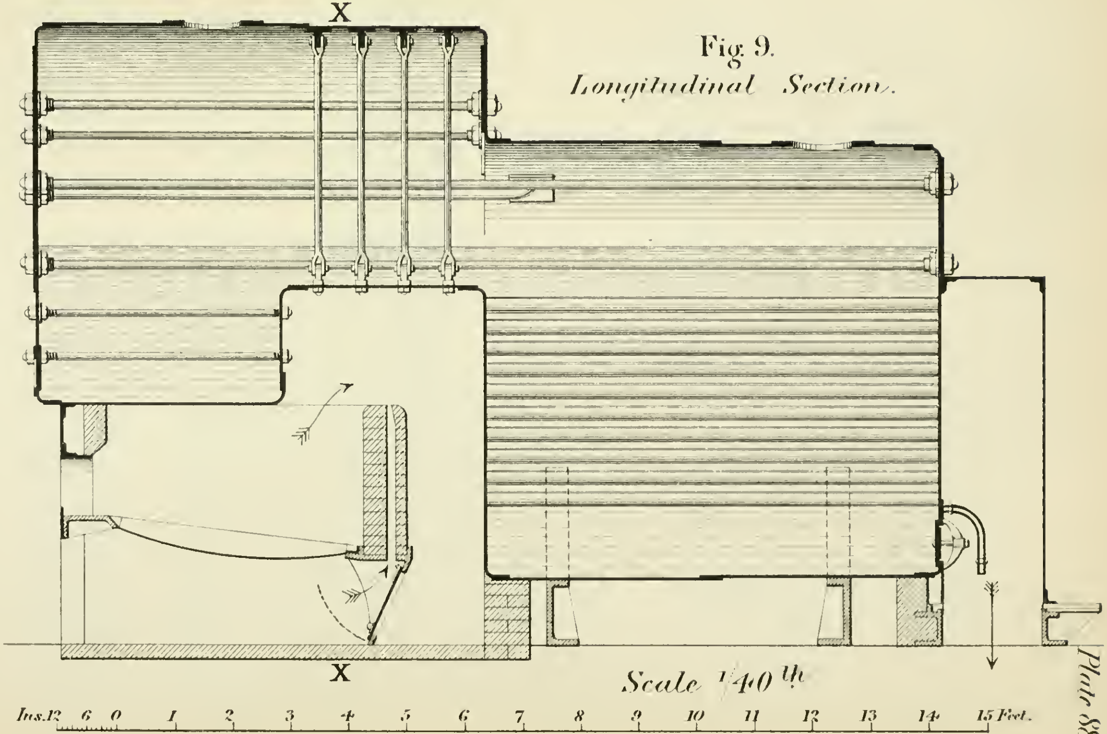
ERIMUS STEEL PLANT.

Fig. 8 *Transverse Section at XX.*



Turner's Marine Boiler.

Fig. 9. *Longitudinal Section.*



Scale 1/40th

(*Proceedings Inst. M. E. 1881.*)

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ERIMUS STEEL PLANT.

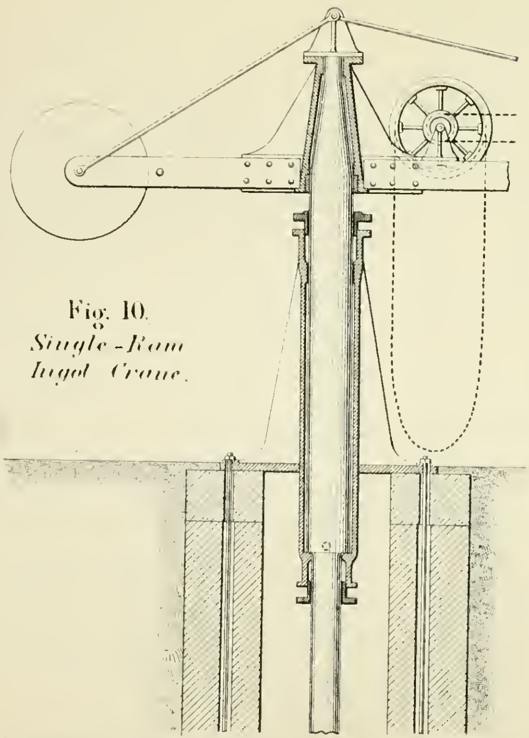


Fig. 10.
Single-Ram Ingot Crane.

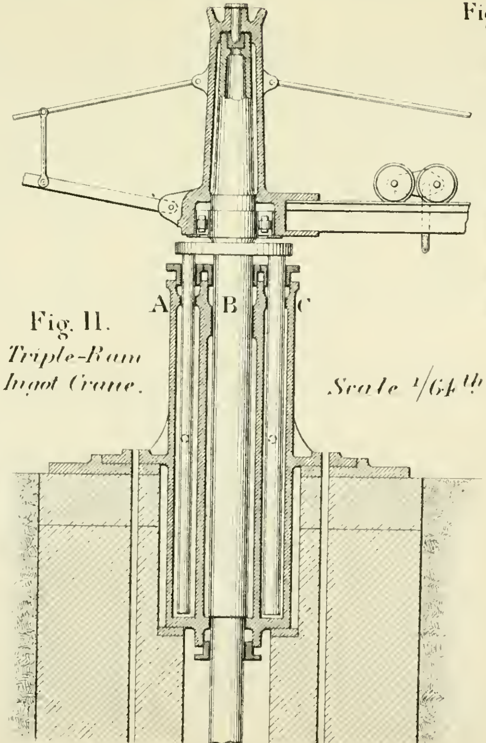
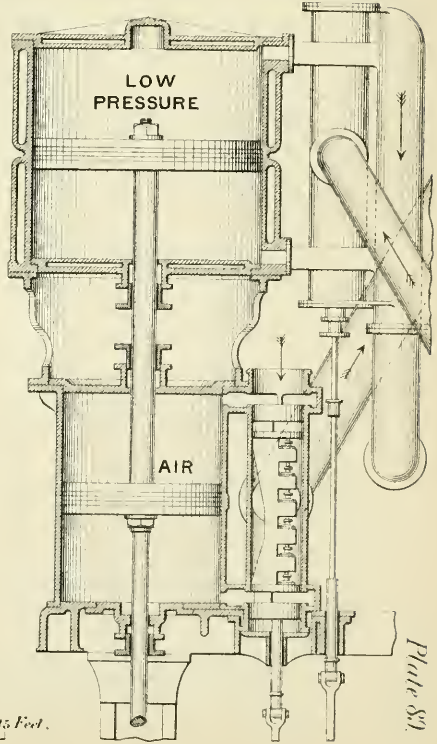


Fig. 11.
Triple-Ram Ingot Crane.

Scale 1/64th

Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet.

Fig. 12. *Section of Steam and Air Cylinders.*

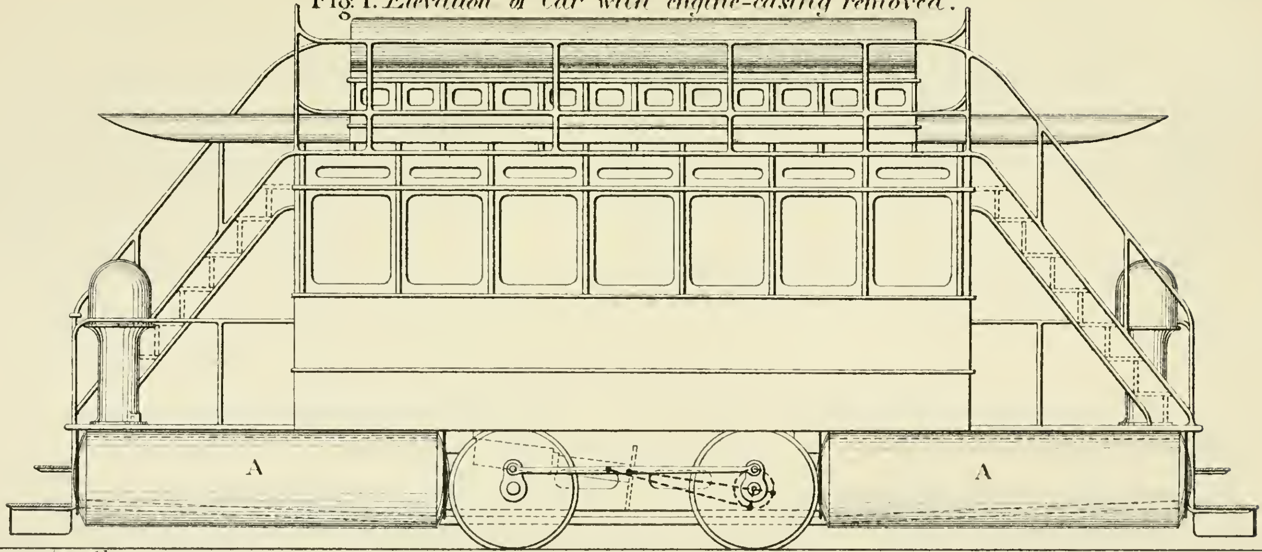


(Proceedings Inst. M. E. 1881.)

Plate 89.

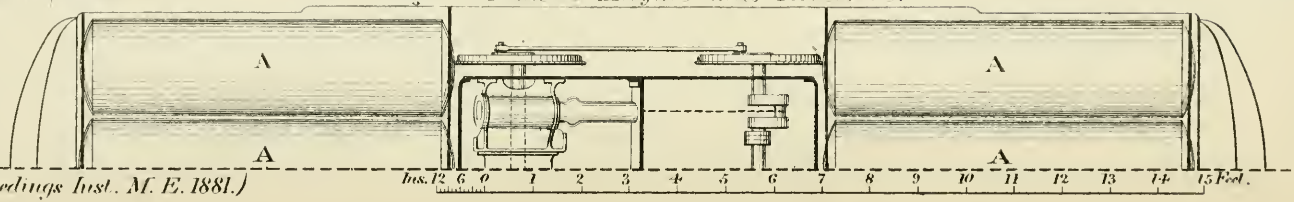
AIR TRAMWAY ENGINES.

Fig. 1. *Elevation of Car with engine-casing removed.*



Scale 1/48th

Fig. 2. *Plan of Engine and Receivers.*



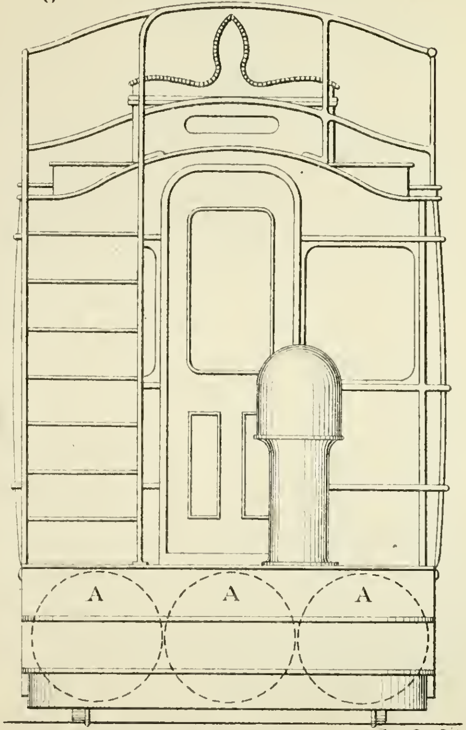
(Proceedings Inst. M. E. 1881.)

Plate 90.

AIR TRAMWAY ENGINES.

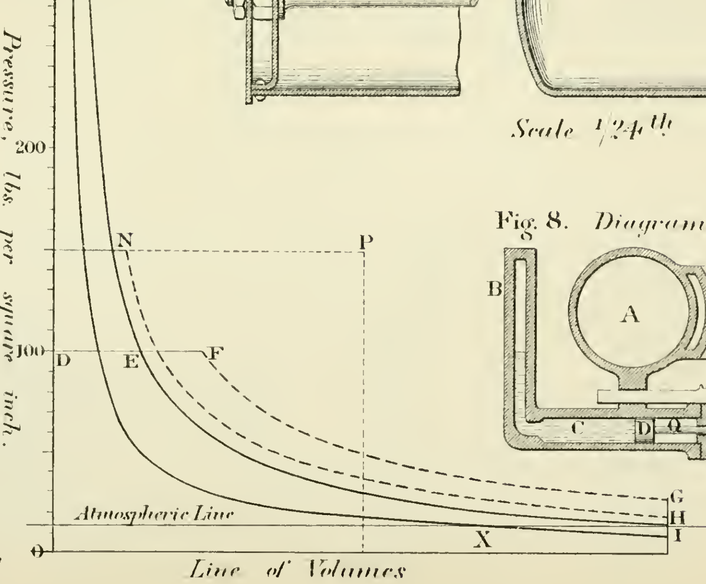
Plate 91.

Fig. 3. *End Elevation of Car.*



(Proceedings Inst. M. E. 1881) Scale 1/36th

Fig. 7.



Construction of Air-Receivers.

Fig. 4.

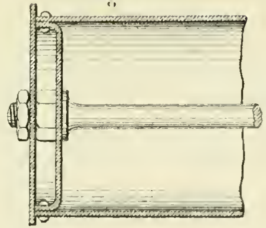


Fig. 5.

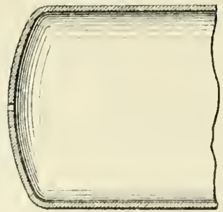
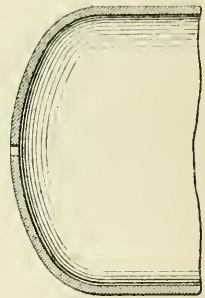


Fig. 6.



Scale 1/24th

Fig. 8. *Diagram of Expansion Gear.*

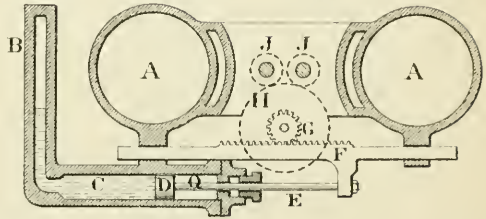


Plate 91.

AIR TRAMWAY ENGINES.

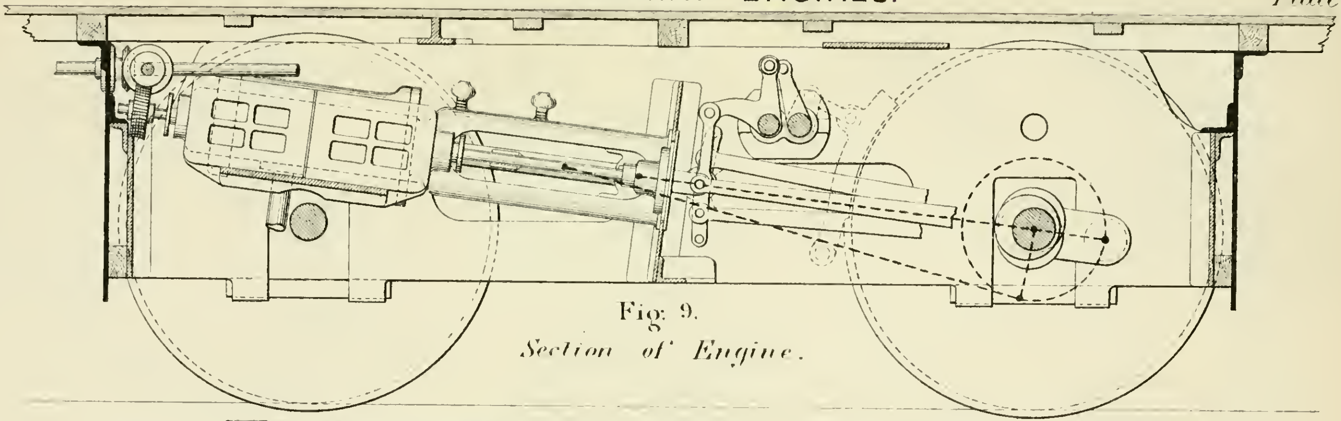


Fig: 9.
Section of Engine.

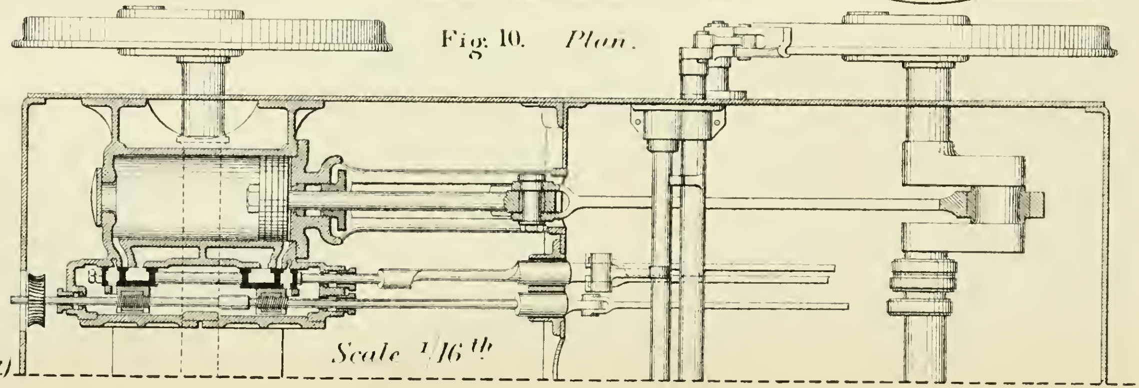


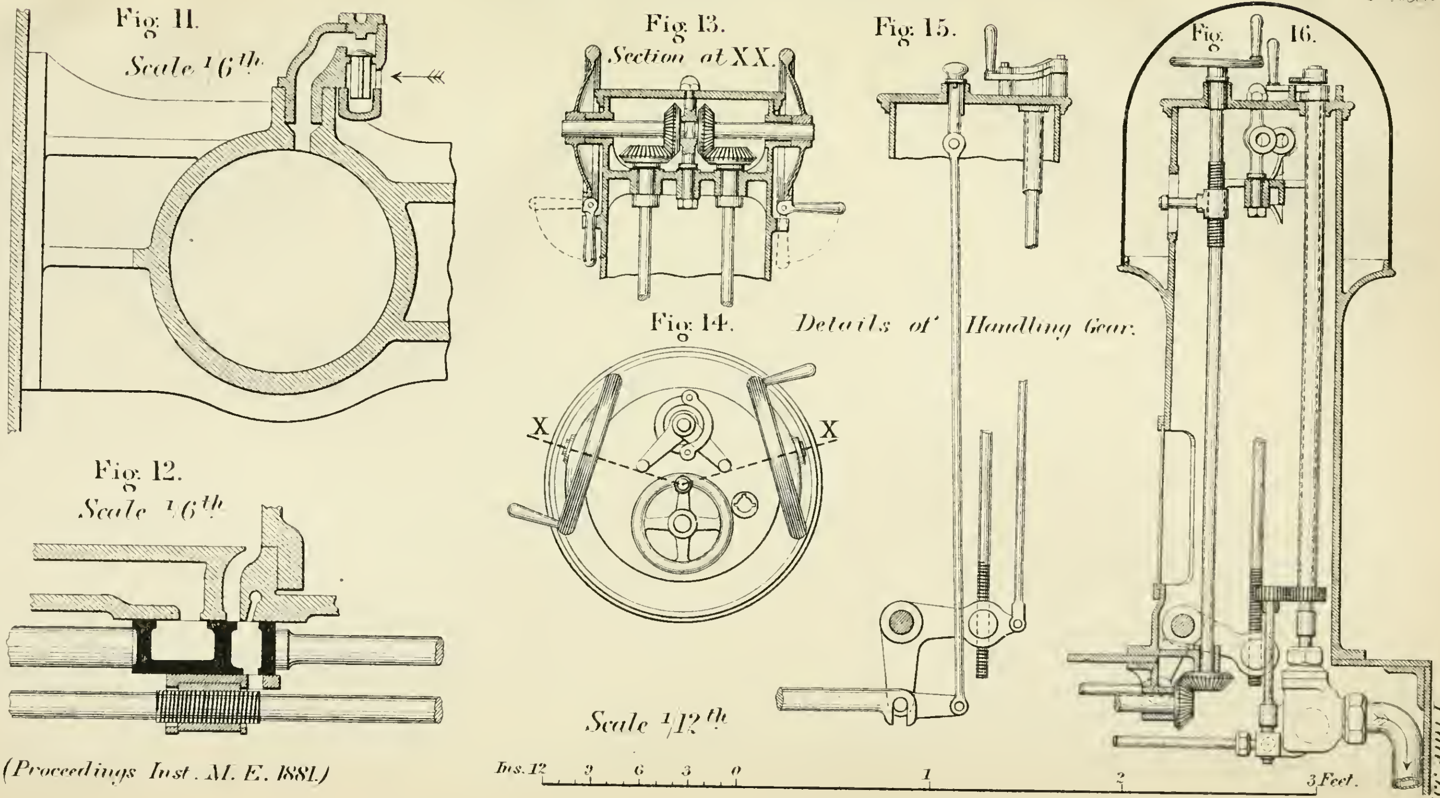
Fig: 10. *Plan.*

Scale 1/16th

(Proceedings Inst. M.E. 1881.)

Plate 92.

AIR TRAMWAY ENGINES.



(Proceedings Inst. M. E. 1881.)

RIVETED JOINTS, SERIES IX.

Plate 94.

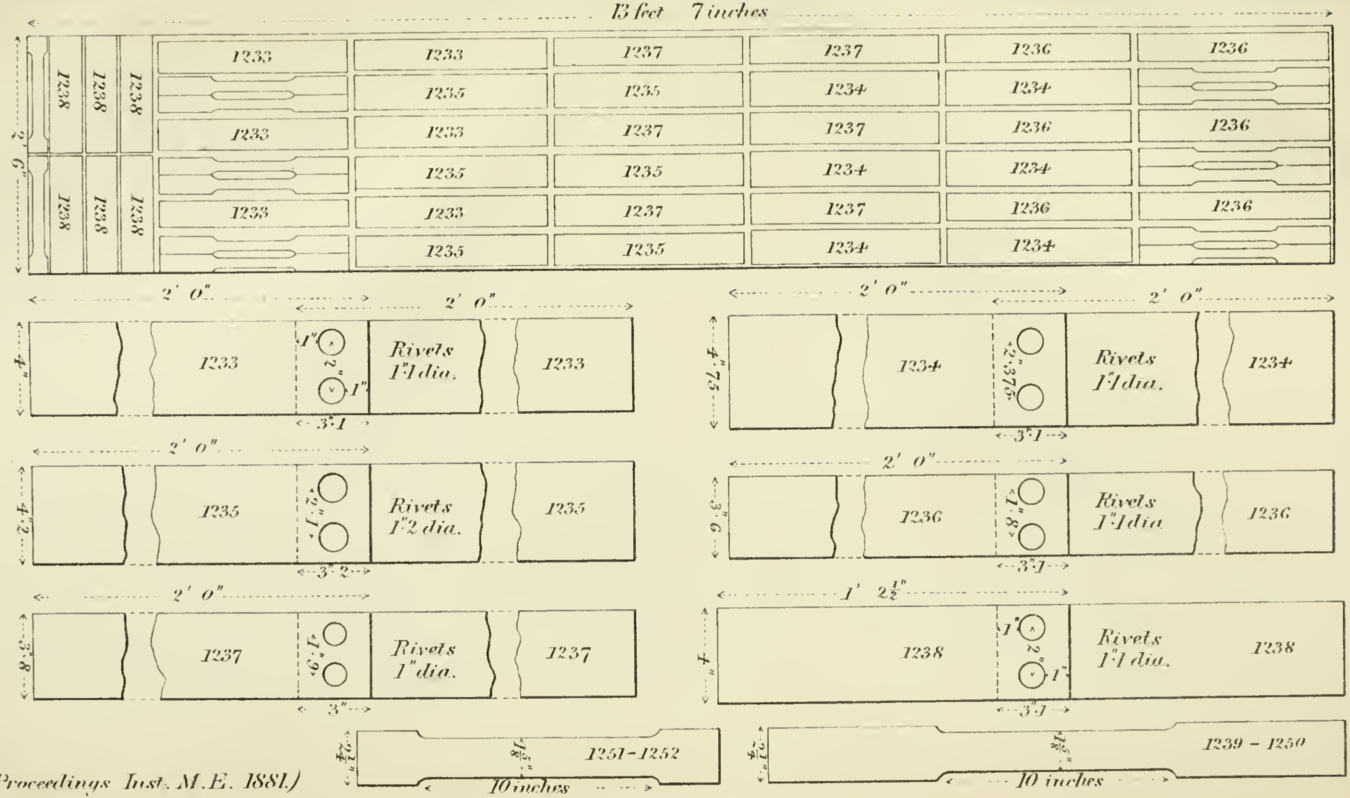


Plate 94.

(Proceedings Inst. M.E. 1881.)